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THE GUANAJUATO MINING DISTRICT, GUANAJUATO, MEXICO.[1]

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[1] The following paper is a work of collaboration. The plan of presentation and the ideas expressed are the work of Mr. Wandke. Mr. Martinez, Federal Inspector of Mines, has offered valuable criticisms as the work progressed and will translate the paper into Spanish.

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GEOGRAPHIC ENVIRONMENT.

Nature of Terrain.—The Guanajuato Mining District is situated in the central portion of the State of Guanajuato which is a part of the great Central Plateau of Mexico. This district shows considerable diversity of relief, as the mountain peaks of the northwest-trending ranges, the Sierra of Guanajuato and the Sierra Gorda, rise from 600 to 1,200 meters above the average height of the surrounding intermontane basins.

The Sierra of Guanajuato, a long anticlinal block-faulted fold in which the ore deposits of this district are found, has a northwest-southeast trend through the central portion of the State. The range rises abruptly from the surrounding valleys or basins and several peaks, as those of San Miguel de los Llanitos (2,831 meters), Cubilete (2,560 meters), La Giganta (2,936 meters) Chichindaro (2,531 meters), accentuate the relief and add to the beauty of the region. To the south of this range and rising isolated above the valley floor is the volcanic cone of Culiacan (3,246 meters). On the north and east the Sierra of Guanajuato is bounded by several valleys or basins, whereas to the south and west is found the great "Bajio," notable for the richness of its soil and sometimes called "the granary of the Republic."

The Sierra Gorda to the northeast of the Sierra of Guanajuato forms the watershed of this plateau region. The waters of its northeast side, tributary to the Rio de Santa María, flow to the Gulf of Mexico; the waters of the northwest side, which include

all the rivers of the State of Guanajuato tributary to the Laja and Lerma rivers, flow to Lake Chapala and thence northwestward by the Santiago River to the Pacific Ocean. The rivers such as the Laja and Irapuato which rise in the mountain ranges of Guanajuato and Gorda have a general southerly or southeasterly trend until they meet with the chief river of this region, the Lerma, which flows westerly to Lake Chapala.

Climate.—The mining region, situated at a mean altitude of about 2,000 meters, has one of the finest climates in the world. The entire year resembles the late spring days of New England. The days are warm but the nights are delightfully cool, and thus, although located in the tropics, cloths suitable for a temperate climate are necessary. During the winter months, as December and January, the evenings are chilly. June, July, August and September constitute the rainy season; the remainder of the year is almost free from rain, and it is indeed a welcome change when the downpours of June begin once more to clothe with green the hills that have been burnt rusty-brown by the hot sun-rays of April and May.

GEOGRAPHIC HISTORY.

Erosive Cycles.—The exact dating of the earliest geographic cycle is uncertain, as no diagnostic fossils have been found to date the basements rocks of the district. The oldest or underlying rocks are contorted shales and schists with intercalated layers and horizons of quarzite and marbleized limestone. Similar rocks are common in this part of Mexico. In the nearby State of Zacatecas, to the Northwest, fossils have been found which establish the age of some of these rocks, at least, as upper Triassic.[2]

Triassic.—What the pre-Triassic geography was cannot be stated, but in upper Triassic it is certain that marine conditions prevailed. Late in this period volcanic activity began with the emission of acidic and basic flows.

Cretaceous.—With the close of the Triassic and perhaps throughout Cretaceous time, the country underwent orogenic

[2] La Industria Minera de Mexico, Distrito de Guanajuato, 1921, p. 18.

movements, the Triassic rocks being flexed into gentle folds. It is probable that the chief event of Cretaceous time was the gradual change from marine to land conditions which, it appears, persisted for this part of the country down to the present time.

Tertiary.—From Tertiary time land conditions prevailed, the detrital accumulations being largely of volcanic origin. The earliest of the Tertiary rocks is a thick formation of red conglomerate of which the constituent pebbles, except those of diorite and granite, were derived from the immediately underlying Triassic and Cretaceous rocks. The fragments of granite and diorite have not been traced to their parent sources; nor has the source of the dense black felsite pebbles characteristic of the conglomerate been located.

The close of the period of deposition of the conglomerate was marked by the renewal of volcanic activity, as shown by the tuffaceous bed, locally called "loza." The "loza" has been classed by the Mexican Geological Survey as part of the conglomerate [8] but careful examination shows it to be a volcanic tuff.

The tuff is succeeded by a series of rhyolite flows and upon these in turn are flows, tuffs, and breccias of andesite. The rhyolite portion of this series is about 400 meters thick as a maximum; the andesite series has a similar thickness. The period of volcanism marked in its later stages by flows of augite and hypersthene andesites and spherulitic quartz-rhyolites culminated in the mountain-building which came near the close of the Tertiary period. At this time were delineated the northwest trending ranges which now characterize this part of Mexico. The cores of these ranges are invariably composed of diorites and granites which intergrade. It becomes increasingly clear, as the district is studied in detail, that the period of compression which resulted in the folding of the mountains was also the time when the granitic rocks were intruded. This was followed by a period of tension, giving rise to the normal faults, now the loci of northwesterly-trending ore-bearing veins. The crustal adjustments

[8] "La Industria Minera de Mexico, Distrito de Guanajuato." Rafael Orozco, 1921, p. 21.

terminated with reverse faults that cut the northwest veins almost at right angles. Along some of them, dikes of andesite have been intruded.

Late Tertiary and Quaternary.—The folded and faulted rocks were subjected to erosion throughout late Tertiary and Quaternary time. This smoothed out, more or less, the major mountains irregularities to a surface suggestive of mature topography, indicating a partial base levelling or halt in the active erosive processes. Animal life must have flourished during this time for bony fragments belonging to the elephant and mastodon have been found in these Quaternary deposits.[4]

Volcanic action did not, however, remain quiescent, for interbedded with the Quaternary deposits are basic and acidic lava flows. These flows, as in the vicinity of Cubilete mountain, cover gravels which are evidently of Quaternary age.

Late Quaternary and Recent.—In late Quaternary time the erosive action of the streams was quickened, as shown by superposed streams flowing in steep-walled V-shaped cañons below a comparatively flat surface. Evidence is being accumulated which indicates that this part of Mexico during the glacial period had a rigorous climate and that snow and ice covered the mountains for the greater part of the year. A paper is being prepared which describes evidences of glaciation in the western Sierras in Durango. But volcanic activity and crustal disturbances have persisted, as is shown by the volcanic cone of Culican of Pleistocene age, the basaltic flows and cones which spread over and dot the great "Bajio" region, the hot springs near the towns of Silao, Apaseo, and Celaya with a temperature of 90°–93° centigrade, and the earthquake shocks which have occurred with considerable intensity as late as 1874.[5]

The following table summarizes the essential features of the geographic history.

[4] "La Industria Minera de Mexico, Distrito de Guanajuato," Rafael Orozco, Mexico, 1921, p. 22.

[5] "Las Minas de Guanajuato." Pedro L. Monroy, Mexico, 1888, p. 348.

Recent	Waning vulcanism Active erosion
Quaternary	Renewal of erosion: rigorous climate Valley filling Mature topography Active erosion
Tertiary	Minor reverse faulting Vein formation Marked normal faulting Reverse faulting and igneous intrusions Mountain building Active and long continued volcanic period Deposition of Guanajuato conglomerate
Cretaceous	Volcanic activity Erosion Mountain building period
Triassic	Volcanic activity Orogenic movements. Beginning of persistent land conditions. Marine sedimentation

Opening of Geographic History.

GEOLOGICAL HISTORY.

The rocks of this district are marine and land sediments, volcanic flows and pyroclastics, and intrusives. The oldest are the marine sediments, perhaps Triassic in age, consisting of interbedded but metamorphosed shale, limestone, and sandstone. These Triassic rocks are overlain by Tertiary and post Tertiary volcanics and their weathering products. See Figs. 1 and 2.

Triassic Rocks.

Limestone and Shale.—The age of these rocks has not been definitely determined since no fossils from them have been reported, but in the neighboring state of Zacatecas are similar[6] rocks of undoubted upper Triassic age. The limestone layers, now largely marbleized, are crystalline blue limestones, carrying from 30 per cent. to 60 per cent. available CaO. The beds vary

[6] "La Industria Minera de Mexico, Distrito de Guanajuato," Rafael Orozco, Mexico, 1921, p. 18.

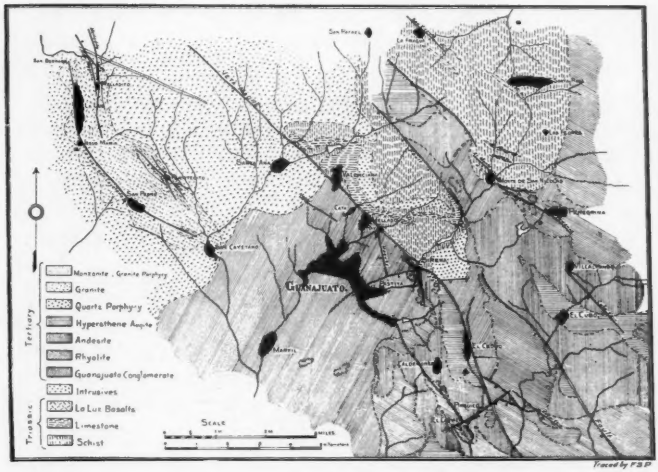

FIG. 1. Geologic Map of the Mining District of Guanajuato.

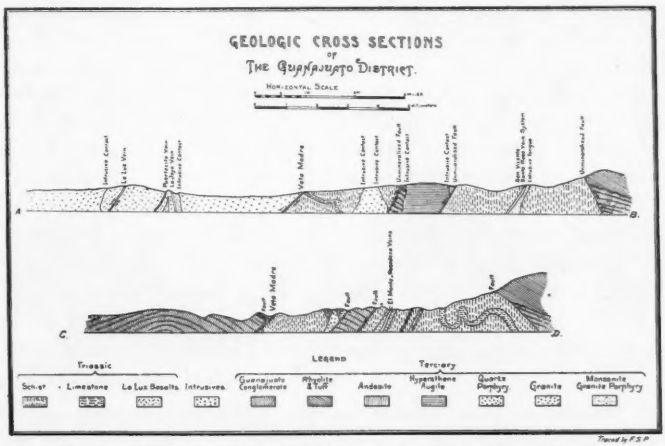

FIG. 2. Geologic Cross Sections of the Guanajuato District.

up to fifteen meters in thickness, the thinner beds being the more shaley. Those exceeding one meter are mined for local consumption in the cyanide plants and for lime cement. The sandstone horizons, rarely over one meter thick, have been altered to quartzite. In some of the sandy layers metomorphism has produced veins of coarse, somewhat opalescent, milk-white quartz that undoubtedly has resulted from dynamic metamorphism rather than from ore-bearing solutions; connate water, pressure, and temperature having been undoubtedly sufficient to produce the transformation. Upon some of these quartzite beds which resemble vein outcrops pits were sunk in the hope of finding ore.

Acidic Effusives.—In the upper part of this series of rocks there are layers of schist that appear at first glance to be more highly metamorphosed portions of the shale. About half way between the City of Guanajuato and Santa Rosa these schists are well exposed and here study showed them to be metamorphosed rhyolite and quartz-porphyry flows. Similar rocks have been cut by diamond drilling in the Nueva Luz properties.

La Luz Basalts.—In the La Luz district there are basic flows, largely basaltic, above the shales. Two shafts, the Tula and the Asunción, passed through the basalts into the underlying black carbonaceous shales. These basalts, resting conformably upon the shales and schists, indicate that the marine sedimentation of Triassic time was brought to a close by the initiation of igneous activity. These flows are about 300 meters thick and show typical amygdular structure and brecciated tops. The term La Luz Basalts is suggested for them. Previously, they were classed[7] as intrusive diorites and as schists derived from the Guanajuato conglomerate. In places the basalts are schisted as Botsford stated, but the typical schisted habit occurs especially where the amygdular tops have suffered dynamic alteration near zones of faulting and intrusion. The La Luz ore-bearing zone is practically surrounded by granitic intrusives and undoubtedly

[7] "La Industria Minera de Mexico," *op. cit.*, C. W. Botsford, Geologist Guanajuato Development Company, 1907. J. A. Church, consulting engineer Peregrina Mining Company, 1908. "The Mines of La Luz, Gto., Mex.," *Eng. Min. Jour.*, July, 1907.

these basalts were locally subjected to great stresses and thus given a pleated appearance.

Intrusive Diorite.—At the foot of the Veta Madre in the vicinity of the Rayas mine were encountered the only rocks that appear to be pre-Tertiary intrusives. They are diorites in the form of stocks and cut the schists and marbleized limestone. Possibly they may indicate the Cretaceous mountain-building period which folded the schists, limestones, and overlying effusives.

Post-Triassic Rocks.

Guanajuato Conglomerate.—The oldest of the post-Triassic rocks is the Guanajuato conglomerate, having a thickness of not less than 600 meters. It is red in color and has been classed as of Tertiary age. Various rocks such as granites, basalts, rhyolites, shales, and limestones are found among the pebbles but the felsitic pebbles are the most abundant. This formation constitutes the hanging-wall of the Veta Madre from the Sirena mine to the Valenciana and in it some of the biggest and richest ore bodies of the district have been found.

This red conglomerate was undoubtedly accumulated under land conditions since in certain sandy layers, ripple marks, raindrop prints, and sun cracks are common; cross-bedding, although carefully looked for, was not found and strengthens the view that the deposit is a sub-aerial accumulation. The sandy layers alternate also with coarse bouldery layers and towards the upper middle portion of the formation there is a horizon composed of boulders up to 50 centimeters in diameter which are both felsitic and granitic, the more basic and shaley types being absent.

The formation owes its red color to limonite that both stains the rock fragments and, along with calcite, acts as the binding material. The formation appears to be a basin formation accumulated between mountain ranges under climatic conditions somewhat similar to those of the arid southwest of the United States, and of northern Mexico. It was probably spread over the intermontane spaces by occasional torrential storms in the form of sheet-floods.

Bufa "Sandstone."—This formation overlies the Guanajuato conglomerate. It has a maximum thickness of six meters and reaches its maximum development just to the east of the City of Guanajuato. Although locally called a "sandstone" the rock is a banded volcanic ash composed largely of acidic fragments with prominent purple-red and pale apple-green colors. The rock being easily quarried and worked, it is used largely for building and ornamental purposes.

Rhyolite.—Overlying the Bufa "sandstone" is a bed of quartz-rhyolite which, in its thicker portions to the east of the city, measures over 400 meters. To the north of the city in the vicinity of El Monte a few isolated fragments of rhyolite resting on conglomerate and intermingled with an andesitic flow is all that marks it. Near the "Presa" on the road to the Cubo mine a cut discloses excellent brecciated flow structure and pillow structure. In places the flow appears to be a mass of oval balls measuring about 30 x 70 centimeters in elliptical section. In the Pinguico mine the main ore body is confined to this rock and gave rise to the idea that rhyolite is particularly favorable to ore. This has now been thoroughly disproved.

This rhyolite contains, in places, innumerable fragments of red-toned felsite that are unlike any part of the present flow and were undoubtedly brought up from depth. They resemble the granules of the underlying ash, and may represent an early cooled phase of the flow formed when the upward progress of the magma was arrested in the vent. The rock is resistant to erosion and throughout the district forms the bold and rugged cliffs which add so much to the scenery. In the Santa Rosa district an unimportant amount of tin oxide has been mined sporadically in this formation.

Andesites and Hypersthene Andesites.—Above the rhyolite is an andesitic formation consisting of tuffs, breccias and flows, which attains a maximum thickness of about 400 meters. This formation in places resembles the green altered phases of the Guanajuato conglomerate along shear zones and veins. Some of the flows are dark-colored and porphyritic and are characterized

by hypersthene. The Mexican Geological Survey classes them as effusives, and microscopic study indicates that such is the case. There are in the district other similar rocks which from their field relations are classed as intrusives.

Quartz-Porphyry.—Overlying the andesites is a quartz-porphyry formation distinguished by its perlitic structure and large quartz crystals. This formation is present only in isolated areas, as Chichindaro mountain, Nayal, and Cerro de Estania. The Tertiary effusive history for this part of the State was apparently brought to a close with this formation.

Intrusive Rocks.

Dike Rocks.—Dikes are common in the formations to the east of the City of Guanajuato and are especially numerous in the vicinity of the Pinguico and Carmen mines. The dikes, rather restricted to the area of andesitic rocks, are predominantly andesitic, although a few are rhyolitic. It is possible that these dikes were the feeders of the overlying flows. So far as known, ore is not associated with or dependent upon them even though there is a marked rock alteration for several meters on either wall. A number of assays were run on this altered rock but rarely was more than a trace of silver and gold found. The Pinguico-Carmen vein cuts several of these basic dikes, thus indicating the dikes to be earlier than the ore.

Hypersthene Andesites.—These rocks are confined to horizons in the andesitic flows, tuffs and breccias. They are dark brownish-black in color and are easily distinguishable from other rocks of the district. They occur at several horizons and appear to cross-cut the thinly-bedded andesite tuffs in small bodies of one hundred meters in diameter as a maximum.

Granite.—To the west of the City of Guanajuato and beginning near the Nueva Luz and Valenciana shafts there is a mass of granite that not only forms the dominant rock on the hanging and foot-walls of the Veta Madre for the next ten kilometers, but also spreads southwest in the La Luz district, underlying the recent effusives that form Cubilete mountain. Narrow tongues, ap-

parently offshoots from the parent mass, cut the schists, shales, and limestones of the Santa Rosa district. The marginal phases of the intrusive are basic, and they range from diorite to quartz-diorite. These marginal phases are veined by granite and also shade off to the central granite. Blocks of diorite project downward into the granite, suggesting that the earliest phase of the intrusive body was basic and that this basic phase was shattered by the upward movement of the later differentiated granite. Some of these basic blocks may be roof pendants but others of smaller size appear to have been entirely surrounded by granite. Along the margin of the intrusive where the La Joya and Melladito mines lie, the basic marginal phase is highly sheeted, the diorite, quartz-diorite, and granite phases alternating repeatedly as narrow layers which, near the contact, are measured in centimeters. Interspersed with these layers are veins of granite-pegmatite and veins composed largely of quartz with minor amounts of feldspar, biotite, hornblende and tourmaline. The contact effects are visible in a zone almost a kilometer in width and offer an interesting study of intrusive action, particularly illustrating the changes from a basic to an acidic magma. Toward the margin, near the town of Santa Ana, basic tongues and dikes cut the granite, indicating that in depth the primary magma was still basaltic.

Granite-Porphyry and Monzonite.—Cutting the granite in a northeasterly direction and visible in it for about six kilometers, is a dike of granite-porphyry having a width of 30 to 50 meters. Where the Melladito vein cuts this dike a low grade silver deposit occurs. Throughout the La Luz district tongues of granite and diorite break through the andesite and diabase flows. The trend of these tongues is more or less parallel to the veins.

In the Santa Rosa or El Monte district the intrusive tongues vary from granite through monzonite and quartz-monzonite to granite porphyry. In that section of the Veta Madre occupied by the Aparecida and Rayas mines, there are tongues of granite-porphyry along the foot-wall of the vein. There is thus in this district much evidence indicating an intimate relationship between

intrusives and ore deposits. This relationship is so clear cut and conclusive that it forms the strongest evidence for the primary (hypogene) character of the silver and gold minerals.

Later Volcanic Activity.

The volcanic history that began in the Tertiary continued, apparently, in this central plateau country, with more or less violence even up to the present. Outbursts of activity characterized by flows of lava have in turn been succeeded by periods of relative quiescence disturbed only by earthquakes. The times of quiescence also appear to have been growing longer and longer so that the present time represents the dying stages of a great period of volcanicity.

That outbursts took place relatively recently is attested by the hot springs along the western flank of the Guanajuato range. These have a temperature of from 45° to 90° C. (some boil vigorously) and are of the sulfurous type, as they smell strongly of hydrogen sulfide. Incrustations characteristic of many hot springs deposits are sparingly developed. The source of the water seems to be chiefly meteoric. Rain waters sink downward encountering rising juvenile hot gases and hot rock material and in turn rise heated almost to the boiling point. Under proper conditions the springs could be exploited as a water cure.

ECONOMIC GEOLOGY.

Pre-Ore Rocks.

The rocks that are definitely pre-ore are the schists, shales and limestones, lower altered basalts, Guanajuato conglomerate, Bufa "sandstone," rhyolite and andesite flows, tuffs, and breccias, hypersthene-andesites, quartz-porphyries, andesite and rhyolite dikes. These rocks are all cut by the ore-bearing veins and have been generally affected by the folding which delineated the northwest trending ranges.

Post-Ore Rocks.

In the immediate vicinity of the City of Guanajuato and the active mines along the Veta Madre, and in the La Luz and the El

Monte districts, there are no rocks younger than the ore-bearing veins. About 15 kilometers south of the City and westward to Mount Cubilete are a series of younger volcanic rocks consisting of quartz-porphyries and slightly more basic varieties such as dacites and trachytes. Similar types are found in the valley towards Irapuato and these younger types are found high in the mountains east of Leon. The hot springs found on the mountain flank from Silao and northward occur along fractures that cut these younger effusives.

Although these younger volcanics do not contain ore deposits in the vicinity of Guanajuato they become ore-bearing further to the northwest where a different type of deposit is encountered, as in the mountains near Leon, where there are several copper-bearing veins. In Las Gigantas mountains, composed of these younger effusives, there have been sporadic attempts to mine a low grade deposit of cinnabar. In the Guanajuato district the ore minerals are largely primary, and secondary enrichment is of negligible importance; to the northwest near the Zacatecas boundary and to the east near Pozos, secondary enrichment is of importance in accounting for the silver values of minable grade. In each of these localities, the deposits that show secondary enrichment are also characterized by an abundance of base metals.

Structure.

To understand the structure of the Guanajuato District, the larger features of the central plateau must be examined. The plateau country of this part of Mexico consists of northwest-trending ridges that rise from 600 to 1,200 meters above the intermontane basins. These ranges represent gentle anticlinal folds which in turn have been block-faulted. The central part of some of these ranges, such as the Guanajuato range, is granite, thus indicating that intrusion accounts in part for the doming of the range. Following the doming of the range and the intrusion of the granite came a period of readjustment, and extensive faulting took place.

Ore-Bearing Faults.—The Veta Madre, which can be traced positively for a distance of not less than 25 kilometers, represents one of the major faults resulting from the relief of strain. This fault begins almost at the southeast nose of the fold and continues as a rotational fault well into the fold; the amount of faulting increases to the northwest. The main fault is located to the southwest of the axis of the fold, is of the normal fault type, and apparently resulted from the relief of tensional stresses that set in after the period of compression and intrusion which produced the fold. While the Veta Madre is the largest of these tensional faults, there are a number of others both on the foot- and hanging-side of this great fault. The most important of these are the fault zones in which are found the La Luz-San Cayetano veins and the El Monte-Peregrina-Cubo veins. The former zone is 11 kilometers into the hanging-wall of the Veta Madre; the latter zone is about 8 kilometers into the foot-wall. In the La Luz zone there are, in addition to the normal or southwest dipping faults, the contra or northeast dipping faults. These contra faults are perhaps reverse faults with a dip of 70° to 80° as contrasted with the 40° to 60° dip of the normal faults. The normal dipping faults to the hanging and foot of the Veta Madre have a slightly steeper dip than has the main fault. Thus the Veta Madre dips at an angle of 38°–45° whereas the La Luz vein dips at 50°–55° and the El Monte vein at 55° to 65°. The three groups of faults just mentioned are all mineralized and in these zones it is almost an axiom that every vein at some place along its length carries a little silver and gold.

Barren Faults.—There are two other groups of faults, both reverse, that are barren and which seem to be post-ore. One of these has a northeast-southwest strike and cuts the ore-bearing veins. The faults of this group are found in the La Luz district cutting the La Luz and Puertecito veins; in the Guanajuato district similar faults cut the Veta Madre in the Sirena and Cardones mines. The second type parallels the chief veins of this district and lies between the Veta Madre and the El Monte vein groups. Its age is uncertain, but because no ore occurs along it the fault is regarded as post-ore.

A third fault period is indicated by the fault zone along the southwest face of the Guanajuato range. These faults cut the younger effusives which form Mount Cubilete, and it is along them that the hot springs rise to-day.

As a summary of structure the following events appear to have taken place.

1. The earth's crust was folded by compression and at the same time granitic rocks were intruded.

2. After the stresses induced by folding and intrusion, a release of the strains took place resulting in normal (southwest) and contra (northeast) dipping faults.

3. Along both of these sets of faults ore solutions rose and deposited the minable ore bodies.

4. After the veins had formed a renewed settling took place, but this time, instead of normal faults indicative of a tensional readjustment, are reverse faults indicative of a compressive readjustment.

5. Much later, apparently, than the veins and the barren reverse faults, was a final tensional readjustment, which produced the scarp along the southwest side of the mountain range and is undoubtedly related to the late period of volcanic activity.

Veins.

Ore-Bearing.—It was stated earlier that the veins of the region occupy faults which followed the doming of the mountains and the period of intrusion. The veins, according to content, fall into two classes, (1) ore-bearing, and (2) barren. From their attitude of inclination they are classified into (*a*) normal or southwest dipping veins, (*b*) contra or northeast dipping veins. The contra veins are found both in the hanging- and foot-wall of the Veta Madre but the most important ones are in the La Luz district where the La Joya, Bolanitos and Melladito veins occur.

Barren.—The barren veins are few in number and there appears to be hardly a vein in this district that does not carry some silver and gold. There is still a tremendous amount of silver disseminated in the narrow veins throughout the district but un-

fortunately they probably will never be considered of minable importance. The barren veins characterized by quartz are best observed in the workings and represent a dying stage of ore deposition.

Ores.

The Guanajuato ores contain silver and gold, commonly in the proportion of one part of gold to every one hundred parts of silver. But there are departures from this proportion, as for example the El Monte, Peregrina, Virgin, and Cubo veins, where gold is present in proportion of from one and one half to four parts to every hundred of silver. There are also in some of the veins local rich shoots of gold ore where gold and silver are equal in amount. As a general rule, when the amount of silver increases say from 500 grams to several kilos per ton, the ratio of gold to silver decreases from the ratio normal to a particular vein.

The ores may best be described as disseminations and bands of silver and gold minerals in a quartz-carbonate gangue. Where the vein is massive, the ground is hard to drill due to the high percentage of quartz. The ore, however, crushes well and forms a clean product well adapted for cyanide treatment. As a rule, the ores may be termed non-pyritic, for pyrite, although always present, rarely forms one per cent of the rock. The base metals such as lead, zinc and copper are present only in traces except for local bunches or shoots.

Minerals Present.

The minerals of these deposits have been carefully studied by Ponciano Aguilar, one of the authorities of this district, whose collection was kindly made available for reference. The local school of mines has also a good collection of minerals to which access was freely granted by the Director. A great many polished surfaces were made and in these the various minerals were identified and their relationships determined. The ores consist of silver sulphides and silver sulphantimonides with which occur, in minor and almost insignificant amounts, such base minerals as galena, sphalerite and chalcopyrite. The gangue minerals are quartz,

calcite, dolomite, siderite, ankerite, and adularite or valencianite. Of rare occurrence in the ore veins are datolite, fluorite, barite, stilbite, apophyllite, and laumontite. (See Table I.)

TABLE I. MINERALS OF THE GUANAJUATO DISTRICT.

Non-Metallic Minerals. Associated with Ore.		Metallic Minerals. Base Metals.	
Silicates.			
x	Amythest		Arsenopyrite
x	Quartz	x	Chalcopyrite
x	Chalcedony	xx	Tetrahedrite
xx	**Valencianite**		Cinnabar
	Asbestos	**xx**	**Galena**
	Apophyllite		Guanajuatite
	Datolite		Marcasite
	Fluorite		Molybdenite
	Laumontite	x	Pyrite
	Stilbite	**xx**	**Sphalerite**
x	Saponite		Stibnite
x	Chlorite		
Carbonates.		*Gold Minerals.*	
x	Ankerite		Native Gold
x	Calcite		Raumonite
x	Dolomite	*Silver Minerals.*	
	Rhodocrosite		Native Silver
	Siderite	x	Argentite ⎫
Sulphates.			Myargyrite ⎪ N Ag_2S
	Celestite		Pyrargyrite ⎬ plus Sb_2S_3
	Barite		Stephanite ⎪
Post Mine Alteration Products.		x	Polybasite ⎭
x	Epsomite		Aguilarite
x	Gypsum		Naumannite
x	Halotrichite	*Oxidation Products.*	
x	Selenite		Embolite
x	Limonite		Cerargyrite
Not Associated with Ore.			Psilomelane
	Chabazite		Marcasite
	Heulandite		

x Common to the veins and abundant.

xx Common to the veins but seen best under the microscope.

Missing from the list of Silver Minerals is one which should correspond to Ag_7SbS_5 and polyargyrite Ag_{11}-SbS_1.

Types of Deposits.

The ores occur in two types of deposits (1) well defined veins; (2) stockworks. The veins may vary from narrow stringers up to 20 meters in width. The stockworks, which are a mass of stringers in the hanging-wall of the main veins, may have a level width up to 100 meters. Such stockworks of minable ore may have as their maximum dimensions a stoping length of 200 meters, a stoping width of 100 meters, and may be followed down the dip for 100 to 200 meters. They are thus large silver ore bodies.

Veins.—The veins of the district show variable lengths and other things being equal, it is almost axiomatic that the longer a

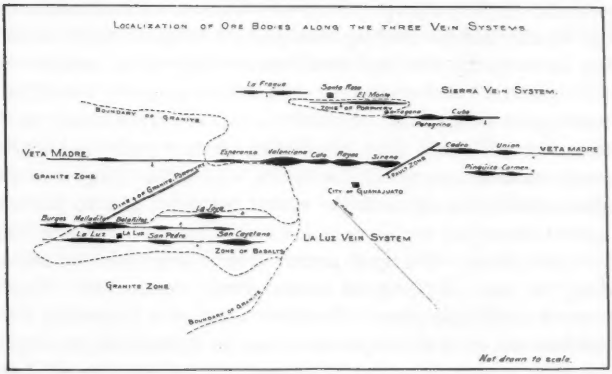

Fig. 3. Location of Ore Bodies along the Three Vein Systems.

vein is, the more likely it will be to carry minable ore bodies. Of all of the veins in the district the Veta Madre is the most persistent and the richest and can be traced for a total distance of 25 kilometers. The chief ore bodies are confined, however, to a section 5 kilometers long from the Sirena mine on the southeast to the Valenciana mine on the northwest. The other important veins can be traced for the following distances: La Luz-San Cayetano, 7 kilometers; Melladito-Bolanitos, 5 kilometers; La

Joya, 3½ kilometers; Puertecito, 3½ kilometers; Pinguico-Carmen, 3½ kilometers; Cubo, 2½ kilometers; Barragana-Peregrina, 3 kilometers; El Monte, 1½ kilometers. The relations of these various veins and contained ore bodies are shown diagrammatically in Fig. 3.

Fissure Veins.—Aside from the Veta Madre the various veins fall into the category of fissure veins. That is, they are filled faults. To picture the formation of a Guanajuato vein the following events stand out (1) a fault occurred to form a pathway; its undulations formed minor variations along both strike and dip. (2) The movement, accompanied by some displacement, produced broken rock material between two fairly well-defined walls or, in places, produced a restricted zone of shattered rock. (3) In case normal faulting took place, a bulge or hump or convex curve on the foot-wall would cause the hanging wall to ride heavily and so produce a tight place which generally would be a barren part of the vein. Similarly concave curves would cause increased space, and thus, by offering an easy pathway to solutions, would be a locus for ore bodies. (4) The rising ore solutions would naturally seek the easiest pathways and so journey upward depositing ore along paths of easy egress, barely touching the tight places. The final pattern would be a series of shoots along the vein. (5) As the solutions rose, replacement of rock material would take place. In places where rock fragments were held between walls this replacement can be traced in all its stages, especially toward either end of a shoot where the processes of replacement stand out with startling clarity.

The slightly shattered zones along a fault permitted the formation of the filled fissure type of deposit with well defined walls. When a well shattered zone was encountered by the rising ore solutions, a sort of stockwork resulted and replacement gave alternations of ore with horses of waste; such places may be from two to four meters wide. In drifting along a vein it is common to cut a series of lenses separated by narrow, tight portions, barren of ore. Usually in a strong vein the barren stretches may be only a few meters long, and in a drift of 200 to 300 meters

fully 80 per cent. of the drift will be in ore. It is customary to think of ground thus mineralized as forming a single shoot. However, where a marked and sharp flattening of the vein occurs, thus causing a convex bulge in the vein, it is common for the values to cease entirely and one may have to pass through 50 to 200 meters or more of barren ground before encountering again a shoot of ore.

The foregoing descriptions apply to the veins such as are found in the La Luz and El Monte-Cubo districts; the Veta Madre, the largest and richest vein in the district, presents a somewhat different picture. This vein was formed along a rotational fault having progressively greater displacement northwestward. Between the Sirena and the Valenciana mines the average displacement is at least 800 meters. The maximum width of this vein is 20 meters. In the old or upper workings for a distance of 400 meters, an average width of five or six meters is common. The features described for the smaller veins repeat themselves here. Along the strike the width of the vein will vary. The strike also varies, a swing to the right going north being succeeded by barren portions just as with the narrow veins, only everything in the Veta Madre is on a grander scale.

Ore Lenses.—There are two types of ore lenses, (1) those with minable vein material from foot to hanging-wall, and (2) those with a meter or two of ore followed by a similar width of waste. There are frequently, in a zone from the foot to the hanging-wall, three lenses of ore separated by two of waste. This has given rise to a belief among the native miners that the Veta Madre consists of three distinct veins separated by waste and that three veins must always be looked for. The belief also gained ground due to a lack of understanding of the geological features of the vein. As a general rule in the vein there are better values along the foot and hanging than in the intervening zone, for it is in such places that there is a banded structure. Such a banded structure was essential to the old miners for only where it occurred could they hand-sort the ore. Along the Veta Madre there is also a mineralized zone in the hanging-wall of the vein. Thus in the

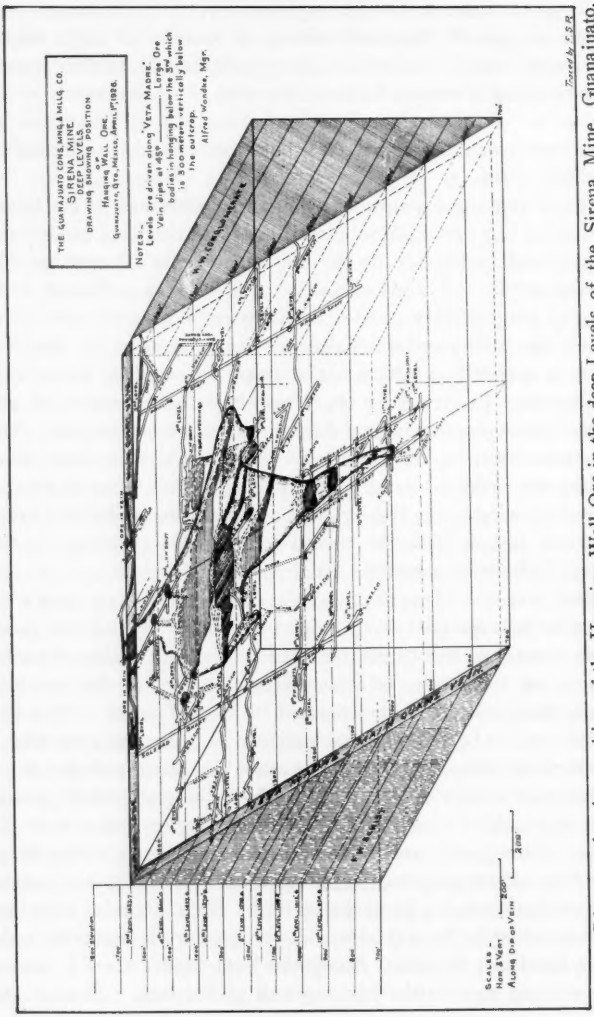

FIG. 4. Diagram showing position of the Hanging Wall Ore in the deep Levels of the Sirena Mine, Guanajuato.

Rayas mine where the early miners encountered the hanging-wall ore it is entirely possible to demonstrate the existence of three mineralized zones or the three veins of early descriptions.

Stockworks.—Just as the smaller veins show a flattening in places along the dip, so also does the Veta Madre. But along this vein, due to the great amount of rotational movement down the dip, it appears that this flattening (causing a bulge or hump along the vein) also caused the hanging-wall to be shattered. Thus, while the hanging-wall wherever prospected in the upper levels shows a similar shattering, it is in depth near where the bulge or hump occurs that the shattered ground became sufficiently well mineralized to be mined for ore.

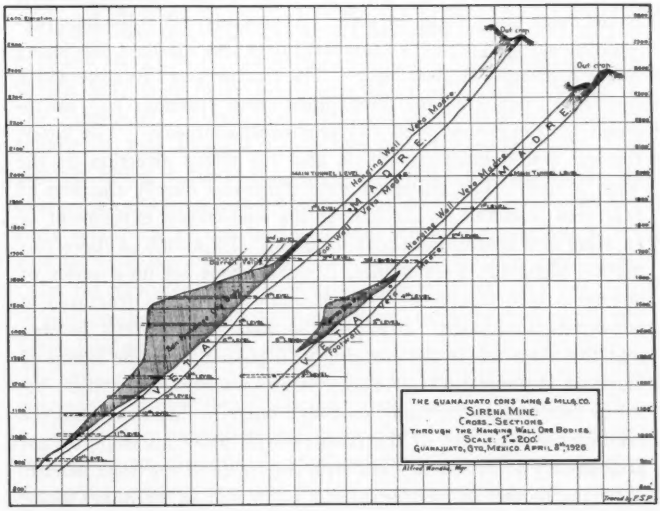
THE GUANAJUATO CONS. MNG. & MILL. CO.
SIRENA MINE.
CROSS SECTIONS
THROUGH THE HANGING WALL ORE BODIES.
SCALE: 1" = 200'
GUANAJUATO, GTO. MEXICO APRIL 8th 1926
Alfred Mendez, Mgr.

FIG. 5. Cross Sections through the Hanging Wall Ore Bodies, Sirena Mine, Guanajuato.

In the Rayas and Valenciana mines the Spanish miners found these shattered hanging-wall areas. It is, however, in the Sirena

mine, where the hanging-wall ore was not discovered until taken over by the present company, and where the work is still going on in virgin ground, that a clear picture is to be had of the ore occurrence. It is here, also, that mining has already gone over 100 meters out into the hanging-wall of the Veta Madre.

This hanging-wall stockwork in the Sirena mine is the place where rich but narrow veins of ore occur and it offers an excellent opportunity to study ore deposition. The larger of these stockworks measures roughly 200 meters long by 60 meters wide in its widest part. From this wide part the stockwork funnels downward for a distance of 150 meters or more to where the minable area measures only a few meters each way.

The formation of this great ore body seems definitely related to the bulge or hump in the vein. Apparently, when the hanging-wall moved with a rotary movement over this hump, a shattering of the hanging-wall took place. The fractures of this zone which now carry ore fall into three intersecting systems; (1) north-south; (2) east-west; and (3) northwest-southeast. The latter, the less well-defined system, is also the strike direction of the Veta Madre. The shattered zone illustrates clearly the sets of fractures produced by Daubree in his well-known experiment of twisting and fracturing a plate of glass. Inasmuch as there was motion along the Veta Madre, it should have set up a series of stresses which would cause the hanging-wall to be fractured at some particular place. It is possible that the place thus favored was the place where the hanging-wall passed over the hump or bulge on the foot-wall. At least there is a close association between hanging-wall ore and foot-wall bulge in this mine, and the ore-bearing fractures of the hanging-wall make an angle of approximately forty-five degrees with the strike of the Veta Madre.

It may be well to mention at this point that in the mines along the Veta Madre there is another relation between hanging-wall ore and the main vein. In the Sirena mine at the third level below the tunnel, or about 220 meters vertically below the surface, the values pass from the main vein to the hanging-wall stockwork. The main vein, continues strong and well-defined in

depth, and has been cut on various levels below, down to the twelfth or bottom level, but the vein, even though 20 meters wide as on the eighth level, remains barren of silver values. There is a condition, therefore, which permitted ore solutions to pass and to replace as much as 20 meters of rock material without depositing any silver in the main vein until a depth corresponding to the third level was reached. But between the twelfth and the third levels, ore was deposited in the stockwork of the hanging-wall.

Vein Formation.

Filling.—The question naturally arises whether these veins are due to filling or replacement. The usual criteria for filled fissures are banding and crustification.

In the Guanajuato district access has been had to each of the principal veins and mines and opportunity has been gained through almost daily work in the mines to study in detail the processes of vein formation. Throughout this work there has been a growing conviction that straight filling has played a minor rôle. By straight filling is meant the filling of preëxisting open spaces by ore. This does not mean that there is no filling, but, in an ore body containing several thousand tons, ten per cent. or less of the vein material is considered as due to filling of former open spaces.

In the stockworks, particularly where the veinlets are only twenty centimeters wide as a maximum, one may frequently observe veinlets full of what appear to be unsupported fragments. The vein walls, moreover, are concordant and the vein material is banded and crustified. These occurrences seem to be due either to the force of crystallization which forced apart the vein walls; to open spaces caused by a solution pressure which forced apart the rock fragments as a dike forces apart its walls; to open spaces left after the ground was shattered; or to a combination of these different causes. It is entirely probable that no single cause produced a given result, but the study of innumerable occurrences has led to a growing belief in the ability of solution pressure, either gaseous or liquid, to force apart the rock walls.

Replacement.—The agency by which practically all of the ore bodies of this district have been formed is replacement. The Carmen-Pinguico vein is a most excellent place in which to study the early stages of vein formation. The vein here is steep, dipping at an angle of 70–80 degrees and on the Carmen property the vein was opened by three drainage tunnels. Along the vein one may see thoroughly fractured or sheeted rock which constitutes the main zone. Over a width of two meters, masses of rock weighing from a few kilos to several tons are separated either by narrow open spaces or by thin veinlets measuring a few centimeters or less in section. This brecciation of the rock represents, perhaps, one of the first things that happened as the vein formed. Under special conditions there was produced a mass of thoroughly shattered rock which suggests that the ore has been mined and the open stope later filled by angular waste fragments. So loose is this material that raises can be run up without using dynamite. Drifts through this material remain open untimbered. The angular and partly-rounded fragments are frequently bound together by quartz and calcite vein material which carries a little silver sulphide. As the vein material is examined closely, one may find here and there fragments of rock in various stages of replacement. Often along the foot-wall or hanging-wall there may be seen a narrow vein, ten to fifteen centimeters wide and a few meters long, composed almost entirely of ore, but even in this narrow vein there are still fragments of unreplaced rock.

Banding and crustification are characteristic of a number of veins, but wherever seen there is undeniable evidence that this banded vein material has replaced preëxisting rock material. It seems that a banded vein formed by replacement as follows: as a result of faulting, crushed rock material occupied the space between the fault walls; ore solutions in rising moved along both foot and hanging-wall and began to replace the broken rock material. Once this process started it continued and the vein material from each wall moved inward giving a banded or crustified vein as the nature of the ore solutions or the conditions for deposition changed. Finally, as the material advancing from each wall met, a comby or crustified structure resulted.

In many of the veins where fragments abound opportunity is given for the study of the stages of replacement. The fragments are usually supported and it seems certain that these merely represent brecciated wall material that has not been replaced. The steps needed to produce a supported fragment were evidently brecciation of the wall rock giving a jumble of rock particles; replacement of rock material by the ore solutions, some fragments going into solution faster than others. The result was to leave the unreplaced or partially replaced fragments surrounded by the newly deposited vein material.

An interesting feature of replacement is the preference shown by the ore for rock fragments. These fragments are frequently seen entirely surrounded by barren banded chalcedonic quartz but are themselves bleached and loaded with pyrite and silver sulphides. Where the sulphides and the carbonates form the cementing material of the breccia there is little tendency for the sulphides to migrate into the rock fragments.

The presence of crustified vein matter would indicate that deposition often began about the fragments rather than by first filling the available openings between fragments. In this connection it is interesting to note the difference in the attitude of the mineral crystals where replacing fragments and where lining vugs that were formed through deposition in a preëxisting open space. In the former case the crystals radiate outward, whereas, in the latter case, the radiation is inward.

Replacement seems to have been a selective process and once a fragment began to be replaced the solutions showed a preference for it over the neighboring particles. Although deposition frequently took place about certain fragments this did not entirely protect them from replacement. The coating of new material undoubtedly slowed down the process of replacement which continued its attack from without inward.

In the replacement of certain fragments the solutions seem to have entered on an irregular front and to have quite generally altered the composition of a given rock particle. Under these conditions the margin of the fragment is shreddy in appearance.

Again, the alteration is confined very closely to the advancing front and either angular (particularly triangular) or rounded outlines are the rule for the unreplaced rock matter. One would suppose that, with an attacking solution, the corners of the fragments, places offering the greatest area, would be the first to go and thus rounded outlines should predominate. Just why angular outlines are preserved and maintained it is difficult to understand unless there is a tendency, under certain conditions, for the rock fragments to present as great an area as possible to solution attack. The fragments showing angular outlines also appear to be more abundant in those parts of a vein where replacement is less intense. This is well demonstrated in certain ore shoots. The narrow beginning of an ore shoot where the assays are low frequently will show slightly altered fragments of angular outline, but as one moves into the shoot where the vein is wider and the silver minerals begin to abound then rounded fragments softened and bleached are of common occurrence.

Along the Veta Madre the action of replacement is more pronounced than along the smaller veins. Along this vein there are numerous places, over a hundred or more meters long, where replacement can be proven to have gone on until a thickness of 15 meters was attained. Such action calls for a tremendous amount of solution.

The foot-wall of this vein is well defined and from this to the hanging-wall the distance may be 15 or 20 meters in the wide parts. This space of 15 meters may be occupied by solid vein material in which occur horses of waste in various stages of replacement. These horses of waste, by their position and orientation, rather conclusively show that replacement has gone on to the extent mentioned. Furthermore, as one studies the end of an ore shoot, the evidence of replacement is even stronger, for the quartz of the vein forks, one stringer from 2 to 3 meters wide staying along the foot-wall and another stringer from one to two meters wide forming along the hanging-wall, the width from foot-wall to hanging-wall being about the same as in the wide vein. The horses of waste between the two branches are usually

thoroughly brecciated and highly altered, the fragments being cemented by vein material, but the entire zone, including the hanging-wall and foot-wall veins and the horses of waste, is too low grade to mine as a unit. The horses of waste may be either brecciated conglomerate or brecciated schists, but in either case are thoroughly bleached and softened, thus indicating that solutions have thoroughly penetrated the rock mass.

Rock Alteration.

Foot-Wall Schists.—The schists are normally dark green to grayish black in color and do not differ from other world-wide occurrences of chloritic or argillaceous schists. As a rule the rock is unaltered, but in places, especially along the richer ore shoots and where zones of fracturing pass into the foot-wall, the schists have become thoroughly whitened or bleached. The loss of color, indicating the alteration of chlorite to sericite, and the addition of a little quartz and carbonate seem to be the most important changes.

Hanging-Wall Conglomerate.—Along the vein where the hanging-wall is typical red conglomerate, this rock, as seen underground, has been extensively altered. In the vicinity of the small veins and for at least 300 meters to the hanging of the Veta Madre the rock has lost its red color and is green, the change being due to the conversion of ferric oxide into ferrous. Locally the alteration has gone much farther, the next step being the conversion of the green rock into a buff-colored one. The change to a green rock is accompanied by the development of chlorite; the buff-colored rock carries in tiny veinlets the feldspar adularia, the chlorite having been converted into sericite. The scale on which the reduction of ferric iron has taken place is tremendous for, merely between the Sirena and Valenciana mines, several billion tons of rock must have had their ferric iron converted into ferrous. The second type of alteration is much less widespread and only a few million tons of rock have been changed to a buff-colored mass. The country rock has thus undergone a widespread and pervasive alteration which would indicate the passage of a great quantity of solution or gas through it.

Ore-veins are found in all of this altered rock and occur sometimes in zones close enough together to warrant mining the ground, but over wide areas some of these veinlets, assaying several kilos to the ton, are so narrow and so few in number as to be of little value aside from indicating the passage of ore solutions.

On a smaller scale, replacement is also pronounced. The best examples are found among the common gangue minerals, of which the most important and widespread are quartz and the various carbonates. In all cases quartz replaces the carbonates and examples of this are found everywhere in the mines. This replacement occurs in two ways: (1) either a bodily replacement of calcite by quartz without any preservation of structure, or (2) the quartz replaces the calcite or other carbonate with preservation of the form and structure of the carbonate. This second type is found in many parts of the different mines and is a wide spread occurrence. The replacement can be traced in all stages from unreplaced calcite which shows the same forms and structure of the quartz pseudomorphs. Thus, calcite occurs in a platy and twinned habit, the plates measuring up to 15 centimeters across by only a millimeter or less in thickness. The identical forms occur in nearby quartz so that the replacement is proved as conclusively as it is possible to prove that one mineral replaces another. It is striking to encounter these masses which resemble well crystallized calcite only to learn on picking them that the mass is quartz, and to find quartz breaking into the cleavage forms of calcite. In many of these quartz masses one encounters cleavage rhombohedrons of pseudomorphic quartz, only the pseudomorphs will be hollow. These hollow forms frequently show minute quartz crystals projecting inward or carry tiny crystals of pyrite. The occurrence is such as to suggest that replacement goes on not exactly volume for volume, but solution begins and deposition keeps pace with it, occasionally going on a little faster and again lagging behind.

At the margins of ore shoots this differential rate of deposition is well shown. Here, it is common to find vugs in greater num-

ber and size than in the central portions of the shoots. The vugs are not due to open spaces formed at the time of brecciation but are quite certainly the result of solution getting a considerable start over deposition. Some of these vugs are large enough to hold a man and one, almost cylindrical in form, had a length of several meters.

The alterations described are considered to be primary. One of the reasons is that iron carbonate is plentiful in the veins and is white in color when first cut by the workings. As soon as exposed to oxidizing conditions the carbonate changes to a yellow or rusty-brown color due to the oxidation of the ferrous iron. Indeed so rapid is this change that in some of the drifts the iron carbonate assumes a yellowish tinge within two hours and has a yellowish-brown appearance within a week. Drifts where this has been observed are dry and the sole oxidizing agent for causing the change is the moisture in the atmosphere. The temperature in these drifts is about 85 degrees F. and the humidity is high. This action would seem to indicate that secondary (supergene) oxidizing solutions have not passed through the vein stuff which oxidizes only after the mine openings are made.

Ore Shoots.

Along all of the veins the tendency is for the ore to occur in definite shoots. The chief cause for the localization of an ore shoot appears to be the structure. On a much broader scale, temperature and pressure conditions appear to have controlled not only the depth to which the ore goes, but also the horizon at which the best ore occurs throughout the district. Bonanza ore has been found at one place or another in each of the various kinds of rock; thus there is no particular kind of rock especially favored as an ore-bearer. However, of two kinds of rock in a single mine it is common to find one more favorable for ore than the other. The important fact as regards ore occurrence is that once deposition or solution started it continued. Several centers of deposition or solution may have been set up at one time but even then there appears to have been a driving force causing material to be deposited

or dissolved. This driving force may have been osmotic pressure which was constantly endeavoring to maintain the chemical equilibrium of the ore solutions.

Trend of Ore Shoots.—In every vein there appears to be a decided pitch of the ore shoots. Thus, along the Veta Madre the pitch is to the south. In the Carmen-Pinguico vein the ore pitches quite decidedly to the north. In the El Monte vein the pitch is again to the south. In the La Luz district a decided pitch is not apparent, but where evident this appears to be to the north in the northern part of the district and to the south in the southern part. The pitch along the La Joya and Melladito veins, both having a contra dip, is decidedly to the south.

The underlying causes for pitch are not known but the direction of rotation of the hanging-wall may play a part. Along the Veta Madre the rotation of the hanging-wall is greater going northward. Undoubtedly the pitch also indicates the easy pathway for the solutions and is also the direction of greatest permeability. Bends and rolls in a vein must also determine or help to fix the solution paths, as must the vein intersections.

The ore shoots seem always to be located in zones that offered the easiest pathway to the ore bearing solutions. Such zones were determined by several factors. In most veins the concave bends in the vein would have tended to form openings as the hanging-wall moved down the dip, whereas, convex portions of the vein, being protuberences, would have acted as points of support. As the hanging-wall moved over the convex hump, a slight almost impermeable gouge would undoubtedly have developed. This supposition holds for the actual occurrence, since in almost every vein studied the best ore is associated with a concave footwall, whereas along the convex portions one may find a narrow tight vein or only a gouge.

Shattering of the rock was important in localizing ore. Good ore is frequently found where veins intersect or where the rock is greatly broken by a network of fractures. Among the narrow veins an ore shoot frequently occurs at the junction of two veins. The hanging-wall ore of the Veta Madre occurs in a stockwork which is a network of intersecting fractures.

The kind of rock has also played a part in localizing ore. On the whole, more ore has been found in the basic rocks than in the acidic, although two of the rich mines, the Pinguico and the Peregrina, contained bonanza ore in rhyolite. Along the Veta Madre the best ore of the Sirena and Rayas mines occurs in the conglomerate hanging-wall and only to a minor extent in the schist foot-wall. But this is only because the hanging-wall rock was better fractured than the foot-wall rock. At Valenciana, where schist forms both the foot and hanging-wall, the greatest bonanza ever found in this district was in the schist hanging-wall. At El Monte, where dikes of granite-porphyry and mozonite-porphyry cut the schists, the ore is in the intrusive close to the contact. Where flows of andesite occur interbedded with the schists the ore favors the andesite. This can be well demonstrated at the El Monte mine where a shear zone cuts the schists, intrusive porphyry and the andesite flows; in the schists, the veins carry only about 45 grams of silver with a gram of gold, but bonanza ore occurred where this same shear zone cuts the igneous rocks. Possibly this may be due to the fact that the igneous rock shattered better than did the schist and so determined the pathway of the ore solution.

Origin of the Ore Minerals.

The origin of the ore in a deposit frequently has a direct bearing upon mining operations. Since very little work has been done upon this particular problem for the ores of this part of Mexico, the subject was studied with considerable interest.

The silver ores of the district consist almost entirely of argentite, pyrargyrite and polybasite always intergrown and associated with pyrite. With these minerals gold occurs either free, combined with silver or as a gold selenide. Chloride and bromide silver compounds, common in the nearby State of Zacatecas, are present only in traces and have been seen only when a most careful search for them was made.

The basic sulphides, although present in all of the veins, are found in but few places in recognizable amounts. In the polished

surfaces of ore from all of the important veins of the district, one may see sphalerite, chalcopyrite and a little galena. In the Sirena, Rayas and Valenciana mines along the Veta Madre, bunches of sphalerite and galena are found, the amount becoming greater as one goes north to the Valenciana where some of the drifts contain an abundance of the base minerals. In the workings of the Nueva Luz property, which cut the Veta Madre on the dip below the Valenciana ore shoot at a depth of 580 meters vertically, base minerals are common. A kilometer to the footwall side of the Rayas portion of the Veta Madre a vein of galena in limestone has been prospected from time to time. In the El-Monte district sphalerite and galena can be found whenever search for these minerals is made. Thus, although base minerals are common in the ores, up to the present time there is no conclusive evidence indicating that the easily cyanided silver ores will give way to base ores in depth.

The gangue minerals associated with the ore are predominantly quartz adularia and the carbonates calcite, siderite, dolomite and ankerite. Chlorite, saponite and sericite are also abundant especially along the margins of the veins. In lesser amounts are found fluorite, apophyllite, datolite and the zeolites laumontite and stilbite.

With this grouping of minerals it becomes at once clear that the ores are characteristic of a primary (hypogene) deposit. The same conclusion is forced upon one in studying the various deposits vertically. At the outcrop one finds the usual limonite-stained croppings. Here silification is common and undoubtedly some of the ore values are present as chlorides and bromides although these minerals are far from common. The ore minerals visible to the naked eye are the silver sulphides and the sulphantimonides intimately associated with quartz. In fact a common occurrence is for silver minerals to be found in particles of colloidal size in veins of chalcedonic quartz. Polished surfaces of such specimens barely resolve the specks of silver minerals. As one follows the veins downward the limonite becomes less and less abundant and pyrite, which is absent in the first two to three

meters from the surface, begins to appear. The carbonates also begin to occupy a more prominent position, but the occurrence of the silver is still much the same. There seems to be no enriched zone near the surface but rich stringers, a centimeter wide and assaying two or three kilos, persist with almost no change from the very outcrop downward in depth. Although the veins have good gossan croppings there is no enrichment of gold associated with limonite.

The heavily oxidized material may persist downward from the surface for a distance of 20 to 30 meters but, below this depth, limonite is hardly more than a stain. At the surface, siderite and ankerite have been largely oxidized but, 20 meters below the surface, carbonates are abundant and, in some of the massive pillars and hanging-wall veins protected from oxidizing solutions, the carbonates are hardly more than stained. The absence of oxidation products in depth and the persistence of the veins from the surface to depth, with no change in the silver-bearing minerals, are further proof of the primary nature of the ores.

The famed bonanza ore of this district brings up the question of its origin. Almost invariably the rich ore occurred well below the zone of oxidation; along the Veta Madre it was from 150 to 300 meters vertically below the outcrop and was found as stockworks in the hanging-wall. Followed upward, the veins of the stockworks become fewer and fewer and the ore minerals less abundant until only scattered barren veins are encountered. It is impossible, therefore, to consider the stockworks a result of secondary (supergene) enrichment, for there was nothing above to be leached out and reprecipitated in depth. As regards the narrow veins a similar condition exists, for they contain lenses of ore which terminate upward in gouge free from oxidized material and vein stuff. Here again, above a bonanza lens only barren gouge exists which, obviously, could not have supplied the metals of the bonanza lens.

Another indication of the primary (hypogene) nature of the ore, is the rock alteration associated with the ore and veins. Two of the great bonanzas occurred in the Guanajuato conglomerate.

This rock, far away from ore, is red in color due to ferric hydroxide; underground, for several hundred meters into the hanging of the Veta Madre, and wherever cut by veins, the rock is green or buff-colored. The green color is due to the conversion of the ferric iron into the ferrous state. This change would necessitate the passage of reducing (hypogene) solutions and not oxidizing (supergene) solutions. Also, the alteration in the wall rock, of chlorite to sericite, indicates that secondary (supergene) oxidizing solutions are not responsible for the accumulation of the bonanzas.

Source of the Ore Solutions.

The source of the solutions which deposited the ore was undoubtedly the intrusive body underlying the great faulted fold in which the ores are found. The granite offshoots of this body are present in many parts of the district. Frequently, as in the El Monte region, the ore follows fracture zones close to the contact of the granite tongues. In the La Luz district, granite occurs close to all of the important veins and a very low grade deposit is found where the Melladito vein cuts and shatters a great dike of granite-porphyry. Along the Veta Madre granite porphyry occurs both in the hanging and foot-walls of the vein, thus indicating a period of intrusion prior to ore deposition. The nothern prolongation of the Veta Madre beyond the great Valenciana mine has granite on both walls. But here, as in many other ore deposits, the values decrease as the vein enters the main body of the intrusive, the ore deposits being more closely associated with the intrusive tongues.[8] In fact, in both the La Luz and El Monte districts, tongues of granite-porphyry are common and the ore deposits are intimately associated with them. It is difficult to escape the conclusion that the magma which gave rise to the intrusive rocks[9] was also the original source of the ore-bearing solutions.

[8] B. S. Butler, "Ore Deposits of Utah," U. S. Geol. Survey, Prof. Paper 80.

[9] The intimate relation between ore and volcanic rocks and the assignment of both to a common source has been well treated by Pedro L. Monroy in his book "Las Minas de Guanajuato," 1888. This book, rarely if ever mentioned in the literature

Nature of the Solutions.

Whether the solutions from which the metals were deposited were acid or alkaline in chemical nature is not known. As judged from the amount of carbonates deposited and dissolved it seems probable that the solutions were alkaline. That the solutions changed in composition is shown by the re-solution of perhaps several thousand tons of carbonate when the carbonate was replaced by silica. That the solutions had a reducing tendency is amply proved by the reduction and solution of several hundred thousand tons of ferric iron which formed part of the conglomerate formation. This reduction may have been accomplished by hydrogen sulphide or some other sulphur compound and part of the iron so reduced and dissolved undoubtedly went to make pyrite which was precipitated later with the vein gangue minerals. This pyrite in part also formed the centers about which precipitation of the silver and gold minerals began, as can be seen in specimen after specimen. This precipitation was probably due to the varying electrolytic solution tension of the metals, the iron of the pyrite driving the silver and gold ions out of solution. This result may have been attained either by direct replacement or by the co-mingling of the silver-bearing and iron-bearing solutions. This latter condition seems to have prevailed whenever silver compounds were precipitated as almost colloidal particles along with chalcedonic quartz.

Temperature of the Solutions.

The temperature of the solutions was undoubtedly that of Lindgren's [10] low and middle zones. Whether the solutions were gaseous or aqueous is problematic. As the pressures and temperatures prevailing were those existing under a cover of several thousand meters of rock, the solutions were perhaps gaseous. If

of the United States which treats of ore deposits, stamps Mr. Monroy as far ahead of his time in considering the subject of the origin of ore minerals. The work shows, that even with limited tools for study, a careful consideration of field conditions and a daily dealing with the facts of actual occurrence will force home the truth of Nature's various ways.

[10] W. Lindgren, "Ore Deposits," 1919, pp. 432 and 513.

the gaseous conditions prevailed the astounding net work of veins in the hanging-walls can be explained, and the thorough soaking of great quantities of rock to produce rock alteration can be better understood. Students of ore deposits seem to have given little consideration, heretofore, to the conception that under temperature and pressure conditions exceeding the critical temperatures of water, the solution bearing the various dissolved constituents is perforce gaseous.[11] Once it is considered that for many ore deposits gaseous solutions must have been active, it is far easier to understand the great penetrating power of the solutions.

Centers of Mineralization.

In many districts of ore deposits there appear to have been centers from which the solutions rose. In this district this conception also holds, but in a broad way. In the El Monte district, along a shear zone of several kilometers, the deposits occur spaced at El Monte, Peregrina and Cubo. Along the Veta Madre, the Valenciana, Rayas, Sirena and Cedro Mines occur spaced and each separated by barren zones. In the La Luz district a similar condition holds for each of the shear zones along which the deposits occur. It is as if, in depth, there was a huge cauldron capable of giving off ore solutions whenever the paths of egress were properly established.

Influence of Wall Rocks.

The district, due to the variable formations present, gives an excellent opportunity for studying this problem. For the district as a whole the chemical nature of the rock is no criterion in determining the development of ore. Rich bodies of ore have been found in all kinds of rock, whether acidic or basic. The Pinguico, Carmen, Peregrina and Nayal ores were found in rhyolite; the Cubo ore in andesite and the Guanajuato conglomerate; the

[11] This point was first brought to the writer's attention by B. S. Butler in 1923, during a conference of the Geological Staff of the Calument & Hecla Mining Company. The subject has been well treated by P. Niggli in his work published in 1922, "Die Leichtflüchtigen Bestandteile im Magma."

Cedro in andesite; the Sirena, Rayas and Nopal in conglomerate composed of both acidic and basic pebbles; the Velenciana in argillaceous and calcareous schists; the La Luz ore in andesitic and basaltic flows.

The most important control appears in all cases to have been not the chemical but the physical nature of the wall rocks. Wherever the solutions found the best channel-ways there they deposited their loads. This is shown strikingly at El Monte where the shear zones pass through schists, basalts, intrusive quartz-porphyries and monzonites. The igneous rocks in all cases were better fractured than the schists. A vein, barren in the schists, will have a workable deposit wherever the igneous rocks were intersected. Along the Veta Madre two great bonanzas were found in the Guanajuato conglomerate, one in the Sirena mine, the other in the Rayas mine. Along the same vein in the Valenciana mine, the bonanza was found in the schists. Were only a single deposit known, it would be easy to infer that a particular rock type was favored by the ore solutions. But, of two adjoining kinds of rock, the type unmineralized is generally the one which fractured less readily. Additional controls appear to have been the kind of rock, temperature, pressure and structure. Under kind of rock one must understand its physical rather than its chemical character. The ore, almost without exception, appears to have been deposited along the easy pathways of egress for the ore-bearing solutions. The control exerted by temperature and pressure appears to have been general. In a broad way the ore does not go below a depth of 600 meters vertically, with the richest ore confined to a depth of 150–300 meters. In considering the localization of a single shoot, structure seems to have played an exceedingly important part. In looking for ore along a given vein concave bends are more favorable than convex, and sudden changes in dip may cause a marked change in values.

MINING.

History of Mining.—Mining work has been carried on in this district since 1548, when a group of packers travelling from

Mexico City to Zacatecas encountered ore in the San Bernabé vein, the principal vein of the La Luz district. In 1550 the Veta Madre was discovered, the first work being done upon the outcrop of the Rayas mine. So rich was this discovery that within the next four years the population became sufficiently abundant to found the present City of Guanajuato.

The early mining was done by building a fire in the face to be advanced and then quenching the heated rock with water. Some of these " fire workings " are still to be seen in a few of the mines. Primitive as this method was, it sufficed to carry on the work in the district until Don José de Sardeneta y Legaspi in 1726–1730 introduced the use of powder.[12] With the introduction of powder the work of exploration was greatly furthered and numerous shafts and tunnels were begun. It was not until 1872 that impure nitro-glycerin came into use.

From the beginning, the mines were in the possession of the Spanish conquerors, the native population serving merely to work the properties. Spain, through the exercise of high taxes, kept a firm grip upon these properties for the first two centuries that the mines were being worked. In the latter part of the eighteenth century the burdensome taxes were somewhat relieved and the mines, not only of Guanajuato but of all Mexico, immediately reflected this by increased production.[13] A report [14] to the Junta de Fomento Administrative de Minería phrased this experience as follows:

> El periódo muy dilatado de más de trescientos años, la experiencia y la razon nos ponen en la clase de verdades prácticas, la siguiente: el trabajo y rendimiento de las minas aumentará a medida que disminuyen los impuestos y el valor de las materias de su consumo.

Early in the nineteenth century, English capital began flowing into this district but, as happened to many of the English com-

[12] " Las Minas de Guanajuato." Pedro L. Monroy, 1888, p. 292.

[13] This point might well be brought to the attention of present day governments the world over, who have apparently lost sight of this lesson of the past.

[14] Mexico, 1847. Documentos justificativos, p. 143. Reference taken from P. Monroy, *op. cit.*

panies which entered Mexico at about the time of Mexican Emancipation, these companies on the expiration of their leases had little but their labors of unwatering the mines to show for their outlays of capital. Towards the middle of the nineteenth century, the mines were operated with great success and profit by the descendants of the Spanish owners, but towards the end of the century, production, especially from the large mines, again fell off. In the last decade of the nineteenth century, American interests came into the district and for the past quarter of a century the work of the mines has been carried on steadily under American supervision.

From 1701 to 1800 the mint records show that gold and silver with a total value of $279,690,689 Mex. Cy. was produced. The production before this time can only be estimated. The years 1800 to 1896 show a total of $405,702,829 Mex. Cy., and 1896 to 1923 $132,603,154 Mex. Cy. It appears, by making an allowance for the missing years, that the district has from its beginning in 1548 up to present times produced a sum slightly in excess of one billion dollars Mexican currency.

In this period even though the grade of ore treated has steadily decreased, nevertheless, due to improved methods of treatment, the advent of the cyanide process, and increased tonnage handled, the value of the product from 1907 to 1914 was greater per year than for any similar period in all of the preceding history of these mines. But even though this excellent record of production was attained, the grade of ore handled has dropped and the profits of operation have decreased to the vanishing point. Lately the Federal and State Governments have shown a tendency to aid the failing industries, but unless new ore bodies are found, the industry of this ancient camp is doomed to be greatly curtailed or to cease entirely within the next ten years, and thus force home the truth that mining is a business dealing with wasting assets.

Mining Methods.—The method of mining followed from the earliest days until the beginning of the twentieth century was that of the buscon system. This system has various modifications. In brief, the company does the work of opening a mine by means

of shafts, manways and drifts. The work of extraction then goes on by turning over a definite part of the mine to a leaser who extracts this ore on his own account. The extracted ore is divided into two equal piles one of which belongs to the company and the other to the buscon.[15] The buscon inspired by the profit some of his neighbors were making kept on sometimes for months before either making a strike or giving up his lease or "campo." One point must always be borne in mind when examining the old workings and fills—the buscon, working for himself, was content with barely a living wage. His time was worth little and he apparently enjoyed the work of sorting ore. One frequently hears, in these old districts, that a great deal of high grade ore must have been left, for the treatment charge made on all ore amounted to 507.8 grams or at the present price of silver $11.00 to $11.50 U. S. Cy. and no payment whatsoever was made for the gold. One might presume that ore slightly in excess of this grade was the lowest that a buscon could possibly handle, and that a great profit awaits the modern mining company. If ore had a habit of occurring disseminated through the vein rock so that any piece one picked up assayed exactly the same as its neighbors then one might well conclude that a great deal of high grade ore was left behind. But unfortunately, it is only in rare parts of a vein that the ore occurs thus disseminated. The usual occurrence of the ore is in eyes or stringers which assay several kilos of silver to the ton and can be easily or readily sorted from the almost barren surrounding vein material. The buscon could break down his vein material, sort out his high grade ore and leave the almost worthless material behind at a cost which compared favorably with the costs of mines equipped with modern machinery. If the vein was very rich the buscon might become careless and only take the best, but usually the buscon did his work thoroughly and left behind material that averaged only from 150 to 200 grams. In other words, unless the vein was wide and rich, the material left behind is barely pay ore to-day. It is only after one has

[15] Frequently, where a buscon had difficulty in making a living the agent of the company advanced the buscon enough to live on.

mined considerable tonnages of material left by the buscons in this district that one appreciates that time meant nothing to the buscon and he did his work with remarkable thoroughness.

To-day, the work of extraction consists largely of mining old fills and solid ground. The chief filled ground is along the Veta Madre where the vein was wide. Due to the angle of inclination of the vein—about 45 degrees—the fills are mined in successive slices about 6 meters apart. Timbered drifts and cross-cuts are put through the fills so as to block out the ore. A retreating system is then adopted to draw the ore. The drifts and cross-cuts are sampled daily as the work advances and some endeavor is made to keep the ore up to grade by leaving low grade blocks and sorting out the barren rock. Of late the Consolidated Company has started a cut and fill system of mining these old fills. The results so far obtained would indicate this to be safer and cheaper than the old slice system. But fills alternately inspire hope and depression as the grade fluctuates. Along the Veta Madre, where perhaps three million tons of fills have been mined, the grade has remained steadily at 170 to 200 grams of silver with 1½ to 3 grams of gold. Low operating and treating costs alone have permitted material of this grade to be mined as the largest tonnage handled by a single company is only 650 tons.

The solid vein is mined either on a shrinkage system or else by using the cut and fill method. A few years ago the shrinkage system was almost universal as is shown by the huge openings left. These holes of late have become a source of danger due to caving ground, and to avoid accidents filling is gradually being adopted. The hanging-wall stockwork particularly lends itself to a cut and fill system. It is common, after a stope has been started, to carry the stope up on its own fill, about half of the material broken remaining behind as waste. This method has the advantage of safety for the men and also a better grade of ore. The men take readily to this system, for it much resembles the work of their ancestors.

MILLING.

Stamps and the cyanide process are generally used for crushing the ore and extracting the values. In the La Luz district the United Mines has successfully and economically treated these silver ores by flotation. The two largest producers, the Guanajuato Consolidated Mining & Milling Company and the Reduction & Mines Company, treat 320 and 650 tons per day respectively. The Consolidated Company has been in continuous operation since 1899 and was one of the first to introduce into Mexico the cyanide process for treating silver ore. Concentrates are made at both of these plants, the Reduction Company shipping theirs to the smelter, whereas the Consolidated treats theirs in their own plant.

The silver values are precipitated from the solutions by using the Merrill and Crowe zinc dust processes. The silver precipitate is then smelted locally into Doré bars which in turn go to the smelter for refining.

The district has been one of the famous silver districts of Mexico having a record of almost continuous operation reaching back for almost four centuries. It is no wonder that the inhabitants look with faith to the future, and believe that ground which has yielded a billion dollars Mexican currency, must indeed yield more. Yet all mines must have an end and unless recent new development work discloses new ore to give a new impulse to the mining industry, then, before the fourth century of its existence is completed, this district will have closed its romantic pages.

GUANAJUATO,
MEXICO.

CORRELATION OF A WELL CORE WITH OUTCROP SANDSTONE.

ROBERT ROTH.

Introduction.

The drilling of the Norma C. Jolliff well No. 1., by the Schermerhorn-Ardmore Company was watched with keen interest by all the companies holding acreage in southern Oklahoma. The well is located in the NE–NW–NW. sec. 24, T. 5 S., R. 1 E., Carter County, Oklahoma. This location places the well on the apex and a little north of the center of the Overbrook anticline, which was reported by various geologists to be about eighteen miles long.

Three oil-bearing sandstones of the Springer formation were expected at a depth of 1,000 to 3,500 feet. They are as follows: the Primrose sandstone series, which was not expected to produce oil, at a depth of 100 feet; the Lake Ardmore sandstone at 750 feet; the Overbrook or City Lake sandstone at 1,250 feet; last, the Castle Rock sandstone at about 2,250 feet. It was mentioned at the time that these depths would probably be exceeded due to the steepness of the dips.

Large asphalt seeps in the vicinity and to the southwest, shown as irregular lines in Fig. 1, as well as the general dip to the northeast, made the outlook for the finding of oil very bright. As conditions surrounding the well seemed to be favorable in every way, according to reports made by several geologists, a number of companies bought acreage in the vicinity. The well with local geology in detail is shown in Fig. 1.

As the well was drilled, numerous shows of gas and oil were encountered and caused considerable excitement at the time. However, the well was abandoned at 4,222 feet. The following note was turned in with the completed log:

"The well was drilled by rotary tools and had to be abandoned because of a fishing job, and collapsed casing at 3,265 feet. The casing collapsed when bailing to complete as an oil well. There was 400 feet of mud still in the bottom of the hole covering all oil sands. The hole filled up 600 feet above the mud with oil of 33 degrees gravity. It had a show for a possible 100-barrel well."

Since the largest show of oil came from a sandstone between 4,065 to 4,086 feet, a core was taken between these depths. As the depth from which the oil was coming was below any producing horizon previously mentioned, and as no massive sandstone had been encountered in the well the question arose as to what sandstone yielded the oil, and if it might be one of the sandstones originally expected. As a result, the core was sent to the author along with a number of samples from the various outcrops of the three sandstones which were expected in the well. Since the Springer formation is quite a homogeneous shale series of some 5,000 feet in thickness and has not as yet been zoned on the bases of microfauna, no help could be expected from that method of attack. Sedimentary petrography was the only available means of attack. On the following pages the author has briefly set forth his method of identifying the core.

RESUMÉ OF REGIONAL GEOLOGY.

The area shown in Fig. 1, together with the Arbuckle Mountains, which lie about five miles north of the town of Springer, is probably one of the most interesting, geologically, in the world. Exposures are abundant and offer splendid sections. From the East Timbered Hill, the highest point in the Arbuckle Mountains, due south to the town of Springer, a distance of only five miles, one may find a continuous section from the Archean to the Pennsylvanian. Along this line the rocks dip to the south at an angle of from 55 to 65 degrees. The total thickness of the section exposed is some 12,200 feet. The stratigraphic column (Fig. 2) shows the subdivisions of all these rocks and contains the most recent revisions by Ulrich and C. A. Reeds.

The main part of Fig. 1 shows the Ardmore Basin situated between two major uplifts: the Arbuckle Mountains on the north

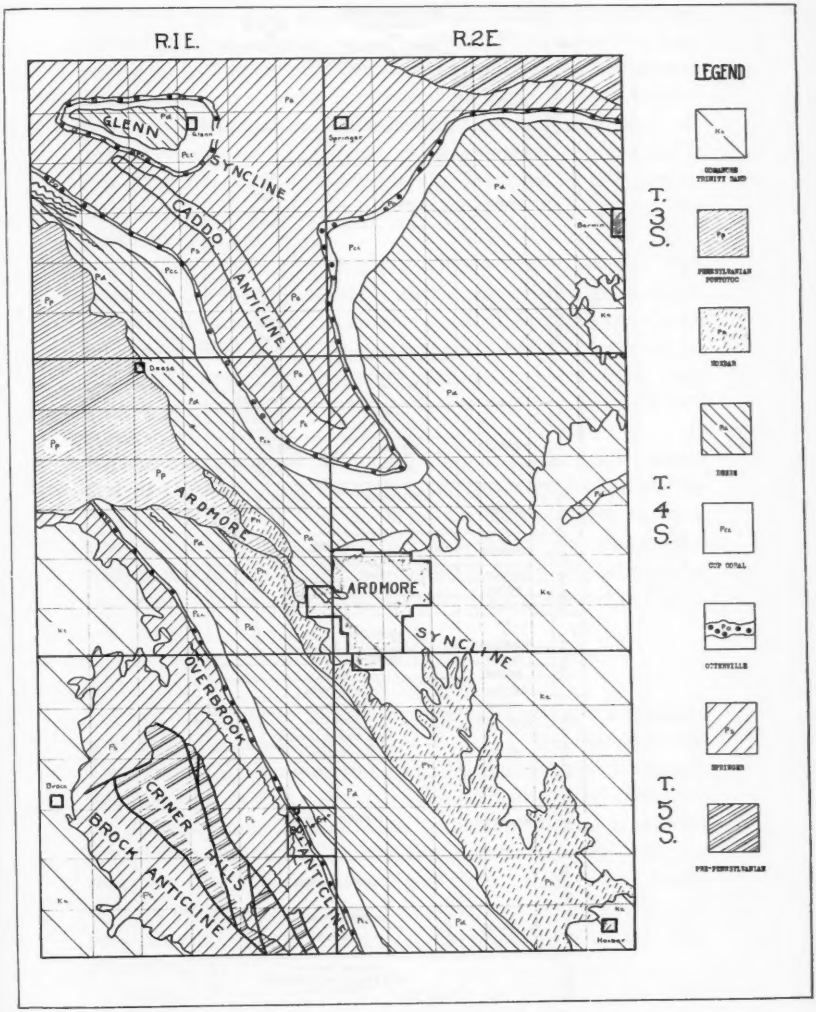

FIG. 1. Regional Map.

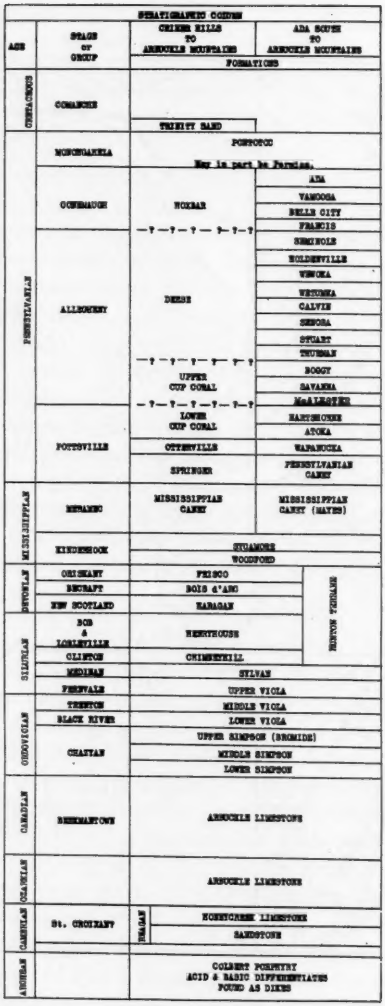

FIG. 2. Stratigraphic column between Springer and Arbuckle Mts.

and the Criner Hills on the south. The whole area has been beveled off until it is almost a peneplane. The sediments composing the basin between these uplifts are of Pennsylvanian age. There is still considerable controversy as to the dividing line between the Pennsylvanian Caney and the Mississippian Caney. As a result the contact is not shown on the areal map. It is possible that some Osage is present below the Meramec in this part of Oklahoma. If present it will be found in the basal part of the Mississippian Caney.

The Criner Hills are mainly a series of fault blocks. This structural condition combined with the marked change in lithology of the Pennsylvanian sediments north of Ardmore when compared with those south of the same town leaves the southern part still largely a matter of conjecture as to specific correlations, since there is yet controversy over the faunal evidence from the two areas.

There is also considerable uncertainty as to the exact correlation of the section of Pennsylvanian formations south of the Arbuckle Mountains with those to the north. Here there is again a marked change in lithology as well as in the faunal associations that suggests a possible barrier of some sort between the two areas. The approximate equivalents are attempted in Fig. 2.

STRATIGRAPHY.

Pennsylvanian.

The Pennsylvanian formations have been strongly folded and apparently lie conformably upon those of Mississippian age. They consist of some 16,000 feet of sediments and practically stand on edge in many places. Subsequent to this diastrophism the Pennsylvanian and all older sediments of the area were eroded to a peneplane. On the east, south, and southwest, the rocks are overlapped by the Comanchean, while on the northwest the overlapping deposits of Pennsylvanian and Permian redbeds rest unconformably upon the upturned edges of the older Pennsylvanian strata.

Springer Formation.—The Springer formation is the basal formation of the Pennsylvanian. It consists of about 5,000 feet

of sediments largely of black shales separated by thin bands and nodules of a brown chert and ferruginous clay that are quite characteristic, and bands of sandstone, and some limestone. About 3,000 feet from the top of the formation is a series of massive sandstones that rim the Caddo anticline and are spaced about 600 feet apart. The maximum thickness attained is about 100 feet. It has been suggested that the base of the Pennsylvanian should come at the base of this sandstone series.

Otterville Limestone.—At the top of the Springer formation occurs an oölitic limestone (Otterville limestone) which is on the average about 70 feet thick and is locally quite marly.

Cup Coral Formation.—Above the Otterville limestone occurs a series of blue shales, sandstones, and limestones. This series make a total thickness of about 2,000 feet and is called the Cup Coral formation. The upper 600 feet is composed mainly of limestones and marls. For about 400 feet below this is a series of blue shales and some thin sandstones, then a series of rather massive, variable, sandstones. The last 500 feet is composed mainly of blue shales.

Deese Formation.—Above the Cup Coral occurs a series of massive sandstones, cherty conglomerates, drab-colored shales and some thin limestone lentils. This series measures a total thickness of around 6,000 feet. The conglomerate which marks the base is locally arkosic.

Hoxbar Formation.—The Hoxbar formation consists chiefly of white sandstones, light blue, yellow and red shales, with some thin limestone members. It is very lenticular in character and measures about 4,000 feet in thickness.

Pontotoc Formation.—This formation, which in part if not all is Pennsylvanian, overlaps with marked unconformity upon the older formations. It is composed mainly of chert and arkosic conglomerates totalling about 1,000 feet.

Comanchean.

Trinity Sandstone.—This sandstone and conglomerate series represents the basal formation of the advancing Comanchean sea

and is about 100 feet thick as a maximum in the area. It thickens to the south.

LOCAL GEOLOGY.

The Overbrook anticline is a dominant structural feature of the Pennsylvanian sediments of southern Oklahoma. It is traceable for some eighteen miles, from sec. 20, T. 4 S., R. 1 E. in Carter County in a southeast direction to sec. 30, T. 6 S., R. 3 E., in Love County. This structure is formed by a thrusting onto, or away from, one of the fault blocks composing the Criner Hills. Dips become progressively steeper as one travels to the southwest since the structure is slightly recumbent in that direction. Dips taken in the vicinity of the Jolliff well show that to the northeast, a distance of about one-fourth mile, a conglomerate dips at an angle of 76 degrees. A limestone close to the well dips at about 64 degrees, while another conglomerate, one-fourth of a mile to the southwest, dips at 90 degrees and is slightly recumbent to the southwest. The strike of all these beds is northwest, and the dip is to the northeast.

The sequence across the Overbrook anticline appear to be monoclinal in the formations above the Springer, but there is a closure in this last formation. In referring to the Caddo anticline mention has been made of the massive sandstones that rim this structure. Since the two anticlines involve the Springer formation principally, and these massive sandstones do not outcrop on the Overbrook anticline, it was believed that they would contain oil and could be reached by the drill at a shallow depth. This idea was also substantiated by the finding of numerous asphalt seeps on the southwest flank of the Overbrook anticline.

METHOD OF PROCEDURE.

The Springer sandstones rimming the Caddo anticline were the ones expected to produce the gas or oil. Twelve samples of these sandstones, along with the core from the well, were correlated. Several of these samples were subsequently rejected upon closer examination as they were either of too fine a grain, or too highly indurated with silica, or both. The physical state of the sand-

stones rejected is such that it would have been impossible for oil to be contained in them, or to have migrated through them since metamorphism took place.

The mechanical and chemical methods of treating the samples before examination will be briefly outlined. The samples were first ground to pass a 40-mesh sieve. Care in grinding is essential, as the object is not to crush the individual grains composing the sandstone but to separate one grain from its neighbor as much as is possible. Following this, approximately the same amount of sample was taken in every case and digested for half an hour in commercial hydrochloric acid and then washed free of acid. This period of digestion was found to be of sufficient length to resolve the larger aggregates of sandstone into its respective parts. If the sandstone is at all silicified, finer grinding is usually necessary. In this case the samples should be ground at least fine enough to pass a 80-mesh sieve before digestion. It is not advisable to grind a sandstone finer than the average size of its component grains. Finer grinding will bring in difficulties which will hinder accurate determinations. After the samples had been washed and dried, they were again screen-sized. This time the material that passed a 100-mesh sieve and remained on a 200-mesh sieve was saved. It has been found by experience that mineral grains of larger size than 100-mesh are difficult to work with and to obtain accurate optical properties with the petrographic microscope. It has also been noted that grains smaller than 200-mesh are too small in many cases to be determined accurately.

This screen-sized residue was next treated with a 50 per cent. solution of nitric acid. This digestion should be brief, as any prolonged action will attack minerals other than pyrite and marcasite. These two minerals are frequently abundant and cloud results. After this treatment a second washing and drying was necessary, after which all the magnetite was extracted by a magnet.[1] The samples were then separated by bromoform and the

[1] In some cases it is advisable to use the magnet on the sample before the treatment with nitric acid, as it has been noted that in drilling hard sands a great deal of the bit is ground to chips of steel which must be removed.

light and heavy crops of detrital and authigenous minerals were mounted upon separate slides of Canada balsam.

The slides were then ready for examination with the petrographic microscope. This examination was done by taking four different fields of the slide and counting the number of grains in each field that represent each different mineral species. The average of the four counts was taken for each mineral and added together. This gave the total number of grains observed in an average field. Then the average of each mineral found was figured on a percentage basis of the whole. The following table shows the percentages of the different minerals observed in each slide. Several other minerals, among which were garnet, staurolite, and brookite, were noted but have not been used. They were found to be very erratic even in the same sandstone horizon.

Minerals.	No. 13.	No. 10.	No. 2.	No. 4.	No. 5.	No. 6.	No. 7.	No. 11.	No. 12.
	%	%	%	%	%	%	%	%	%
Anatase Authigenous	00.00	00.00	00.25	00.09	00.00	00.20	00.00	00.00	00.10
Zircon Euhedral	01.50	03.10	04.00	01.90	04.30	03.10	01.40	05.70	04.20
Anhedral	12.50	08.80	21.10	27.10	10.10	09.40	03.00	24.10	19.70
Ilmenite	16.50	19.40	12.70	19.20	06.50	23.50	01.40	08.50	38.00
Leucoxene	47.80	49.20	43.20	35.20	69.80	21.60	79.70	48.70	33.10
Tourmaline	21.00	17.70	12.40	09.70	01.80	34.80	12.60	08.00	03.80
Rutile	00.60	01.20	06.00	05.10	03.60	07.00	01.00	03.90	00.50

INTERPRETATION OF THE TABLE.

Upon examining the relative percentages of the minerals in each column it will be noted that there is a closer agreement between numbers 10 and 13 than between any of the others. (No. 10 was a sample of Overbrook sandstone and No. 13 was the core from the Jolliff well.) The agreement is so close that there can be little doubt that the two sands are very nearly the same. This correlation places the well core in a certain horizon of the Overbrook sandstone member of the Springer formation. The reason for the apparent disagreement found in comparing the results of the various samples

taken from the same sandstone may be explained as follows: The core taken from the well did not represent cuttings taken across the whole thickness of the sandstone penetrated, but was a core representing only a part of the total thickness. As a result of this the samples were taken with the idea of comparing individual parts of a sandstone member and not with the idea of comparing the whole member with another whole member of the same sandstone.

ATLANTIC OIL PRODUCING CO.,
TULSA, OKLAHOMA.

A GENETIC COMPARISON OF THE MICHIGAN AND BOLIVIAN COPPER DEPOSITS.

JOSEPH T. SINGEWALD, JR.

AN ore deposit is as it is because of two groups of factors. It is an expression of the nature of the mineralizers that introduced its valuable constituents, and it reflects the geologic environment in which the mineralization took place. In interpreting the genesis of an ore deposit, we must differentiate those features which are an expression of the inherent nature of the mineralizers from those features that result from the accident of geologic environment. The differentiation is complicated because geologic environment may influence profoundly the behavior of the mineralizers, and the same geologic environment behaves quite differently under various conditions of mineralization. To arrive at an explanation of the genesis of an ore deposit involves, therefore, not merely a determination of facts of observation, but also the subjective element of the weighing and interpretation of facts. This inevitably leads to differences of opinion. One investigator picks out certain characteristics of an ore body, considers them essential factors in the genesis of the deposit, and sets forth an explanation based on those characteristics. He observes other deposits that exhibit those same features, though they may differ in many other features, groups them all together, and speaks of a type of ore deposit to which they belong. Another investigator recognizes the same characteristics in those deposits, but interprets them as due to some common features of geologic environment and, therefore, as nothing more than accidents of coincidence. More fundamental in their significance, in his opinion, are certain features in which the deposits differ. Consequently he arrives at divergent genetic conclusions for the deposits and breaks down the type.

PREVIOUS INTERPRETATIONS OF NATIVE COPPER DEPOSITS.

The native copper deposits of Michigan and the copper deposits of Corocoro, Bolivia, are examples of such buffeting about of genetic interpretations and conclusions. Let us survey briefly how the standard literature in economic geology has handled these deposits. De Launay and Beyschlag, Krusch and Vogt have grouped them together under native copper deposits, although the latter authors say the Corocoro deposits occupy a special position in the group because they contain no zeolites. The thing that stands out to them is the unusual common feature of the occurrence of the ore as native copper without searching critically whether that is merely the result of geological environment or whether it is inherent in the nature of the mineralizers. Beck places the Lake Superior deposits in veins of carbonates and zeolites with native copper and Corocoro in the non-committal category of bedded copper deposits. Lindgren also does not consider the two occurrences genetically alike. The Lake Superior deposits are called deposits of native copper with zeolites in basic lavas, and mineralization is considered to be genetically related to the lavas. The Corocoro deposits are classed as concentrations from surrounding rocks. These conclusions seem to be arrived at largely because of certain features of the geologic environment of the two deposits. Lane has placed both occurrences in one type of native copper deposits and enumerates six common characteristics of the type, the essential ones of which I have shown do not apply to the Corocoro deposits.[1]

Nearly all who have studied the Lake Superior deposits have emphasized their association with the basic igneous rocks and have interpreted the genesis as tied up with that association. Van Hise, Leith and Steidtman wavered between a genetic connection with the effusive rocks or with a more remote magmatic source in intrusive rocks, but concluded that the effusive rocks were more likely the source of the copper-bearing solutions. The

[1] Joseph T. Singewald, Jr., and Edward W. Berry: "The Geology of the Corocoro Copper District of Bolivia." The Johns Hopkins University Studies in Geology, No. 1, 1922, pp. 76–78.

details of the explanation of the origin of the deposits were worked out in different ways by the different workers, but all hinged on an immediate genetic relation between the ore deposits and the associated igneous rocks.

Until recently I had not seen the Lake Superior copper deposits, but had twice had the opportunity of visiting the Corocoro district. Comparing my interpretation of the genesis of the Corocoro deposits with the general drift of the genetic interpretations of the Lake Superior deposits, I had arrived at the conclusion that the two occurrences were fundamentally unlike.

INTERPRETATION OF COROCORO DEPOSITS.

The Corocoro deposits might be described as follows: Two series of sedimentary rocks, made up in part of volcanic debris, dip away from each other on opposite sides of a fault. The series on one side is prevailingly shale, that on the other has more numerous and thicker intercalations of sandstone and conglomerate. Ten miles west of Corocoro and fourteen miles to the north, at Comanche, igneous rocks have been intruded into the sedimentaries. The rock at the latter locality, a diorite porphyry, is identical lithologically with fragments of igneous rock found in one of the sedimentary series. Hence the general period of igneous activity was more or less coincident with that of the deposition of the sediments. A number of the porous sandy beds are impregnated with copper ore on each side of the fault, and there was some deposition of ore in the fault plane itself. The dioritic rock lies in a belt of dioritic intrusions that extends across Bolivia from north to south. Copper mineralization has occurred at a number of other points along this belt. With these facts in hand, present-day orthodox reasoning would lead to the conclusion that the Corocoro mineralization represents an impregnation of porous beds along a fault plane by ascending cupriferous solutions coming from an underlying dioritic magma. The conclusion would be accepted as an adequate and satisfactory explanation of the genesis of those deposits and would be challenged only by the unorthodox.

But we can go a step further in the description of those deposits. The ores occur in red rocks that are bleached where mineralized, and the ore mineral is native copper. The orthodox now balk at the explanation also; they separate the deposits from those that are supposed to be formed in the regular way by ascending magmatic waters, they look around for unusual explanations, and set up a new type of ore deposit. Would it not be more logical to reason first in this way: Copper deposits are generally formed in rocks other than red rocks, and consist of ores other than native copper. Suppose the same kind of mineralizers that produced the copper sulphide ores entered red rocks, what kind of ores would be precipitated? Bearing on the chemistry of this mineralization is the fact that ferric iron was reduced to ferrous iron, and the iron may have been in part or wholly removed. The ferric oxide of the red rocks exerted, therefore, an oxidizing effect on the mineralizers. If they were of the usual composition of metalliferous solutions, sulphates would be formed. In the presence of iron, lime, and magnesia, the sulphuric acid radicle would combine with them, and the copper be precipitated in the native state. If sulphur were in excess of the available ferric oxide, the copper might be precipitated in part or entirely in the usual form of the sulphide.

At this point one more item can be added to the description of the Corocoro deposits. In addition to the native copper, much copper sulphide was precipitated. And, where the ores consist of copper sulphide, the copper content is so much higher than that of the native copper ores that during the last few years the major part of the copper production of the Corocoro mines has come from the sulphide ores. The mineralizing solutions that deposited the Corocoro ores were capable, therefore, of depositing and did deposit copper in the sulphide form. There is no need of assuming a source for them or a character radically different from that of the usual magmatic copperbearing mineralizers. The unusual feature at Corocoro is that mineralization occurred in a geologic environment that is not often encountered. The native copper ore is a result of that environment. Hence, I set

forth the conclusion that the source of the mineralizing solutions may be ascribed with reasonable certainty to an underlying dioritic magma of which the Comanche rock is an offshoot.

INTERPRETATION OF MICHIGAN DEPOSITS.

At the Ann Arbor meeting of the Society of Economic Geologists in 1922, L. C. Graton presented conclusions of the Calumet and Hecla Mining Company's geologists that represented a complete departure from the general trend of previous genetic interpretations of the Lake Superior copper deposits. At that meeting I presented the foregoing review of my conclusions concerning the origin of the native copper of Corocoro and made the following comparative analysis of their reasoning as the basis of my belief in the correctness of their conclusions as against the validity of previously held theories. They recognized the same geologic features of the Michigan deposits that were recognized by their predecessors, but they attached a different significance to them. What earlier investigators interpreted as features of genetic significance, they ascribe solely to geologic environment. The interpretation is in a measure subjective; it involves a difference in opinion concerning the meaning of facts of observation. The impartial observer can do no more than weigh the conclusions against the observations, and accept the more probable and the more plausible. The theory that looked to the basic lavas as the source of the copper and to a large extent of the mineralizing solutions was inherently weak. Thus Van Hise, Leith, and Steidtman, though they accept the theory, remark "there are perhaps fewer parallels elsewhere of the deposition of metallic ores in quantity from surface extrusive rocks than from intrusives." The theory gained credence because the deposits were thought to be inherently different from other copper deposits and were believed, therefore, to have been formed in a different way.

The geologists of the Calumet and Hecla Mining Company attached a new significance to old observations and added new observations of importance. The ores are associated with amygdaloids, brecciated lava tops, and interbedded felsite conglomer-

ates not because the lavas supplied the metal and the mineralizers, but because this geologic environment furnished channelways of high permeability to mineralizing solutions. They found that maximum ore deposition took place where the mineralizing solutions were converged against impermeable barriers or impounded by textural and structural features. Zeolites are absent in the conglomerates and are subordinate in amount and not especially intimately associated with the copper in the other rocks. Hence, they concluded there is no inherent connection between zeolitization and copper deposition. These facts are all in harmony with a theory of mineralization by magmatic waters derived from the underlying gabbroitic magma. That such waters did circulate in the region is demonstrated by the deposition of copper sulphides where the geologic environment was different. The main ore deposition happened to have taken place, however, where solutions entered rocks characterized by a preponderence of ferric iron. Even though these solutions were ordinary magmatic waters carrying copper potentially as the sulphide, the copper is not likely to have been precipitated in that form. The ferric oxide of the rocks was reduced, the sulphur of the solutions was probably oxidized, and hence the copper could be precipitated in the native form.

Last July I had the privilege of spending a few days in the Lake Superior district under the able guidance of Dr. T. M. Broderick, geologist of the Calumet and Hecla Consolidated Copper Company. It was evident that the relation of the copper of Lake Superior to the basic lavas was environmental and not essential. The native copper had been precipitated where the mineralizing solutions had circulated in an environment of ferric iron, and ore deposition was accompanied by reduction of ferric iron, clearly shown to the eye by the blanching of the rock. That the solutions under other environment might have deposited sulphides and arsenides was indicated by minute quantities of chalcocite and by veins of arsenides like domeykite and algodonite closely associated with the native copper.

CONCLUSIONS.

The features shown by Dr. Broderick and emphasized by him as of essential genetic significance are those of significant importance in the Corocoro district, and the two districts are mutually corroborative of the deep-seated source of the mineralizing solutions in each. The red rocks at Corocoro and in Michigan are significant features of difference between those districts and other copper deposits. The ferric oxide of the red rocks of Corocoro and Michigan made possible the deposition of native copper from ascending magmatic waters. This feature explained, all other features are in harmony with a mineralization by such waters. At Corocoro there are no basic lavas to which the mineralization can be ascribed. The theory of magmatic waters from an underlying source is there inescapable. The origin of the Michigan ores is adequately and reasonably explained in the same way.

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REVIEW OF THE RADIOACTIVE MINERALS OF MADAGASCAR.

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THE use of radium and thorium in the arts, industries and pathology is now thoroughly established and is likely to be extended in the future. Other rare elements of the rare earths are beginning to have value in the making of alloys and for other purposes. Still other rare elements for which no practical use is known at present may easily be of importance in the future. It is, therefore, worth while to get together all the data available concerning the occurrence of these rare elements in nature. The deposits of Katanga can now furnish all the radium for which there is a market, but as these deposits will sometime be exhausted, it is likely that minerals containing less radium will be extensively exploited later on. The same may be said of the thorium minerals, now being chiefly obtained in India and Brazil.

The following notes are derived chiefly from the fine monograph by the well known French Mineralogist, Alfred Lacroix, on the Mineralogy of Madagascar.[1]

Madagascar, a French Territory, lies in the Indian Ocean between parallels of 12° and 26° south latitude and thus is almost wholly in the tropics. The island trends in a northeasterly direction, with a length of about 985 miles and a maximum width of about 362 miles.

The west third of the island and a narrow strip at its south end are composed of sedimentary beds of Permian and later age, with numerous areas of post-Jurassic volcanic rocks. The central and eastern portion of the island are composed chiefly of

[1] "Mineralogie de Madagascar," vol. I., 1922, vol. II., 1922, vol. III., 1923, Paris. Unless otherwise stated all the analyses and determinations of radioactivity are taken from Lacroix's monograph. The calculations of the radium and thorium metal contents of the minerals were made by the author.

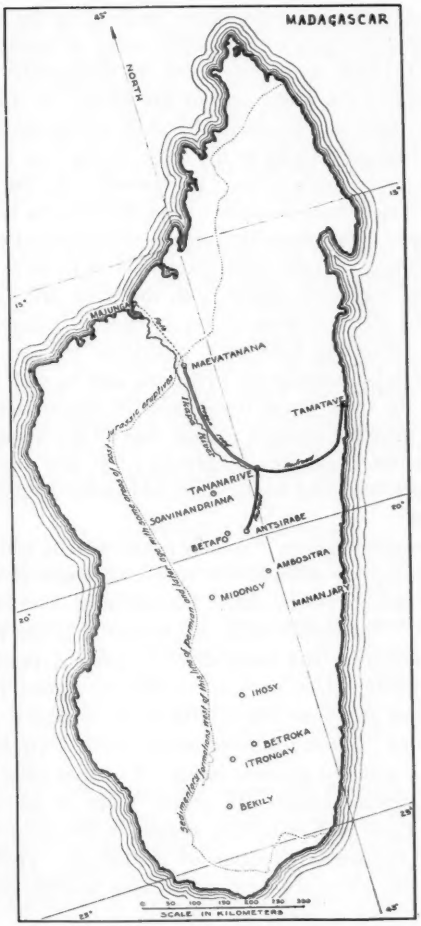

FIG. 1. Outline map of Madagascar.

older crystalline rocks, with some areas of post-Jurassic volcanics, and narrow fringes of sedimentary rocks along the east coast.

This extensive area of crystalline rocks is essentially mountainous. It stands up sharply above the sedimentary area to the west, except in the south part of the island. It appears to be limited by faults and an essential feature of the central part is a high cliff running parallel to the coast, at the foot of which are found the same schists as upon the summit. To the east of this cliff these schists form successive steps down to the neighborhood of the ocean. The crystalline area is characterized by an abundance of ridges with an orientation from N.E. to N.W., and in consequence numerous valleys with the same orientation. The rocks of the area are more or less gneissic in texture, the dominant type containing little mica, sometimes without mica, with generally some amphibole or pyroxene, and banded rather than schistose. In some places these rocks are accompanied by very micaceous schistose gneisses passing into mica-schists, associated with quartzites, crystalline calcareous rocks and silicified rocks derived therefrom, and finally with feldspathic amphibolites and pyroxenites.

This vast gneissic area, originally constituted of schists, quartzites and calcareous sedimentary rocks, has been penetrated by various intrusives, cut by dikes, mechanically deformed and recrystallized. The complication is augmented by the presence of numerous massives, and many dikes of granite, pegmatite, diabase and gabbro, which have not undergone metamorphism and which possess the same characteristics as similar rocks of the gneissic series. These unaltered intrusive rocks are regarded as of later age than the gneissic series. The later basic rocks are perhaps contemporaneous with similar rocks of the mica-schist series or perhaps with those that abound in the sedimentary formations of the western portion of the island. Their extreme freshness leads one to regard them as being possibly of Mesozoic age or even more recent.

THE RED EARTH (TERRE ROUGE).

In Madagascar, as in all tropical countries, the rocks have been subjected to great decay, and the recent formations, red clays, éluvions (fragmental deposits) and alluvials cover much of the crystalline area. The granitic and gneissic rocks, pegmatite dikes, and other crystalline rocks are softened by decay but preserve to a greater or less extent their original texture. It is only at the top and very near the surface that the original texture disappears.

The Grand Isle is essentially a country of red earth, of lateritic clays. These products of decomposition are generally colored yellow by oxide of iron for a certain distance from the surface, but become red where exposed to the action of the sun, hence the name, TERRE ROUGE. The topography of the red earth areas is characteristic with round topped ridges and valleys with flat bottoms. The minerals originally disseminated in resistant rocks are chiefly found concentrated in these recent soft materials from which they can easily be extracted with the pick.

THE RADIOACTIVE MINERALS.

The uraniferous ores of Madagascar may be divided into two groups: the first comprises those of primary origin and these are the most abundant, and are found chiefly in potassic pegmatites and to a much less extent in sodic pegmatites. The second group contains only autunite, more or less bariferous, formed by the decomposition of primary minerals and in the single commercial deposit near Antsirabe evidently transported from a distance.

The primary radium ores are essentially niobates (sometimes titaniferous) of yttric earths and uranium with accessories of the ceric earths and thorium minerals. The minerals are fergusonite, euxenite, samarskite, blomstrandite and priorite-blomstrandine, with three minerals found only in Madagascar; viz: betafite, samirésite and ampangabeite. All of these minerals have the same family appearance with a greasy luster and strong refring-

ence on their fractures. If their determination is not always easy for the specialist, it follows that it is difficult for the prospector. Fergusonite presents square, acute, pyramids. Euxenite and priorite always, samarskite frequently and ampangabeite more rarely, present orthorhombic pyramids.

FIG. 2. Showing areas of uraniferous pegmatites.

Betafite, blomstrandite and samirésite are nearly always in distinct crystals, octahedrons or rhombododecahedrons. These crystals are sometimes isolated and imbedded in mica, sometimes form large masses, contrary to what one finds with the other uranium minerals which are generally in isolated crystals.

The intensity of the radioactivity does not suffice in itself to determine the mineral from different deposits, as the uranium and thorium content shows considerable variations. The radioactivity is less the greater the content of water and varies in different samples from the same deposit. In the case of thorium, the hydrated mineral appears to show greater radioactivity than the unaltered mineral.

MADAGASCAR RADIOACTIVE MINERALS.

Allanite (*Orthite*).—A ceriferous epidote, containing in Madagascar some thorium, due to which it is generally radioactive; Lacroix restricts the name allanite to the little crystals tabular following *h'*, while orthite is used to designate the very large black crystals often altered by hydration, and he writes a somewhat different formula for the two varieties. The specific gravity of the orthite is 4.5 but falls to 2.5 by hydration. These two minerals are found in potassic pegmatites associated with euxenite. They should not be confounded with tscheffkinite which is similar in color, but which gives color reactions for titanium. Allanite in microscopic crystals is found at a greater number of places in granite. On the route from Tananarive to Anjozorobe the granite is pitted with little red stains in the center of which are crystals of allanite.

Orthite occurs in pegmatite in Madagascar, as in Norway, in large black crystals with brilliant greasy luster, often weighing several kilograms but which are generally without crystal faces. In the croppings the mineral is generally altered. Blocks of it from the Red Earth are fragile and exteriorly of a clear yellow or brown-red color. In the newly discovered deposits in the region of Lake Itasy, the large crystals are associated with betafite, orangite and malacon and the orthite is much hydrated, of a brown-red color with a feeble translucidity which gives it the aspect of diadochite. The crystals are much fissured and disintegrated, leaving a chambered skeleton of the same color, which is very characteristic of the orthite of Madagascar. The radioactivity as determined by Orcel varies from 0.01 to 0.16, and at Belamosina, Sama and elsewhere it shows no radioactivity. To the S.W. of Betroka, orthite is associated tscheffkinite.

Ampangabeite.—A new orthorhombic mineral, the crystallographic forms of which recall samarskite. Color red-brown to brownish-black, with very striking greasy luster. Specific gravity 4.29 to 3.9 according to the degree of hydration. Essentially a niobate of uranium with tantalic and titanic acids and some ceric

earths. Decomposes in HCl with yellow solution and UO_3 reaction. The low content of TiO_2 separates ampangabeite from (1) the aeschinite-polymygnite group, and (2) the euxenite-polycrase group. It is, moreover, distinguished from (1) the first by its low content of ceric earths and from (2) the second by low content of yttric earths. Radioactivity 0.3 to 0.6. Found in potassic pegmatites at Ampangabe, also at Ambatofotsikely.

In two localities it is found in rectangular prisms of some cm. in length; crystals often grouped with axes imperfectly parallel and with curved faces that cannot be measured. Associated with columbite, monazite and ilmen-rutile. It is also found in pegmatite associated with columbite at Miakanjovato and Andreba.

Autunite (*Uranocircite*).—A micaceous orthorhombic secondary yellow calcium-uranium phosphate, formed from primary uranium minerals, sometimes in the pegmatite itself and sometimes at a distance from the primary minerals, as at Antsirabe, where it is found in peaty layers in alluvial beds in sufficient quantity for exploitation. All of the Madagascar autunite contains some barium. Specific gravity 3.05–3.19. Very radioactive.

The composition is as follows: P_2O_5 15.5 per cent.; UO_3, 62.7; CaO, 6.1; H_2O, 15.7. Part of the CaO often replaced by BaO, and when completely replaced forms uranocircite (specific gravity up to 3.53). Autunite is found in a great number of pegmatite dikes in Madagascar, frequently implanted on betafite, euxenite or samarskite, at the expense of which it is formed. Found at Maharitra, Antandrokomby, and Ambolotara. Beautiful crusts of the mineral of a canary-yellow color occur at Mt. Kinjabe in the region of Ankafotra. Spangles of autunite are described by Rasamoel as being found in pegmatite intrusive in gneiss 9 km. S.S.E. of Vinaninkarena.

Betafite Group.—Under this name, Lacroix includes a group of isometric minerals, which except blomstrandite, have been thus far found only in Madagascar in pegmatite and which exist in sufficient quantity to constitute an ore of uranium and radium. This group, comprising betafite, blomstrandite, and samirésite,

should be placed in the crystallographic system with pyrochlore from which it differs in its richness in uranium with little of the alkalies and fluorine. These minerals generally contain traces of bismuth and lead. All of these minerals are unfortunately hydrated and no formulas can be established with certainty; only by chemical analysis can they be identified. All possess analogous physical properties. The crystals of betafite and samirésite are generally octahedral or rhombododecahedral; color brown-green, by hydration yellowish. Specific gravity 5.0 but falls to 3.75 by excessive hydration. Lacroix considers these minerals essentially niobates or niobotantalates of uranium with various bases and containing variable proportions of titanium. Blomstrandite contains much tantalic acid, while betafite and samirésite contain but little. Samirésite differs from betafite by its richness in lead, its less content of titanium and absence of lime. The content of H_2O varies from 5 to 12.5 per cent. in the samples analyzed. Unlike most of the unaltered niobates, these minerals are readily attacked by acids and are distinguished from other niobates by the above mentioned properties, their isometric crystallization and high radioactivity.

The betafite group of minerals occur chiefly in potassic pegmatites and the first samples were found in searching for beryl. At Ambatofotsy, the decomposed dike material has been washed for betafite. It is found in place in the dikes and is concentrated at points rich in biotite. Some of the betafite crystals weigh several kilograms and one group of crystals was found weighing 104 kilograms. Associated minerals are euxenite, orthite, priorite and malacon.

Betafite is also found abundantly in small crystals at Maharitra, Vohimasina and elsewhere in soda-lithic pegmatites.

Blomstrandite is abundant in a beryl-pegmatite at Tsaramanga in the form of octahedral crystals up to a dimension of 5 cm. and also in the Red Earth. This mineral is often associated with black crystals of columbite and smaller crystals of malacon.

Blomstrandite.—See Betafite Group.

Columbite.—Although not generally a radioactive mineral, a

sample from Ambatofotsikely analyzed by Duparc, Wunder and Sabot [2] showed a content of 2.02 per cent. of U_3O_8.

Columbite in Madagascar is one of the characteristic minerals of the potassic beryl-pegmatites and at Anjanabonoina is found in a soda-lithic pegmatite, where its chemical composition is normal.

Euxenite.—This orthorhombic mineral is the most widely distributed of the titano-niobates of Madagascar and it is likely that the island can furnish a greater quantity than any other region. With the exception of a single deposit at Yohimasina in the Sahatny Valley, where Lacroix found euxenite in a soda-lithic pegmatite, it occurs in potassic pegmatites accompanied by muscovite, beryl, monazite, betafite and sometimes columbite, and at Andaombatotany by samirésite.

Fergusonite.—This tetragonal yellow metaniobate of yttrium with cerium, uranium and thorium, etc. is found in some potassic pegmatites south of Lake Itasy, with euxenite at Fiadanana in beautiful crystals; with betafite and euxenite to the west of Ambatovohangy and elsewhere.

Hachettolite.—A single crystal of the size of a walnut accompanied by tourmaline crystals was given Lacroix from the west of Mt. Bity. An analysis by Urbain, showed a content of 14.15 per cent. of U_3O_8 and 2.37 per cent. of GlO. This last oxide has not been found in other minerals of the group.

Monazite.—Lacroix first described monazite in place in pegmatite in Madagascar. Since then many other deposits have been found and the island can perhaps be said to furnish the largest and most beautiful crystals known. Most of the primary deposits are found in potassic pegmatites with beryl, often intimately associated with mica and often 10 cm. or more in greatest dimension. It is found in alluvial deposits at Ambahy derived from syenitic pegmatites with bastnaesite and tscheffkinite. The beryl deposits of Ankanzobe are rich in fine crystals of monazite. At Ankazot-sifanatra, the crystals reach to 600 grams in weight.

[2] *Bull. Soc. francaise de Mineralogie,* vol. XXXVI., 1913, pp. 15–17 and vol. XXXVII., 1914, pp. 19–30.

Lacroix described a new sort of contact deposit at Ambatoarina. Here the limestone, metamorphosed by granite, contains monazite and imerinite, a form of aegerite. The monazite in the limestone is always microscopic, but in the associated pegmatite dikes, with calcite, celestite, ambatoarinite (a new carbonate of strontium with ceric metals) quartz, microcline, albite, etc. the monazite crystals are 1 mm. in size and form also agglomerations of minute grains.

Priorite-Blomstrandine.—The orthorhombic minerals of this group form a series having the same chemical composition as the euxenite-polycrase series; the niobic types form priorite, and the titaniferous blomstrandine. The facies of the crystals is very different from those of the euxenite-polycrase series; instead of being elongated following *c*, they follow *a* and are flattened following *g'*, or equally developed following *b* and *c*. Priorite is radioactive. Found in pegmatite at Tongafeno, and at other places in the Red Earth.

Pyrochlore (*Microlite*).—In the granitic rocks containing aegyrine and riebeckite at Ampasibitika, Lacroix found microscopic golden yellow octahedrons, accompanying zircon. Having isolated some of these crystals, he found they contained little titanium and refers them to microlite.

Samarskite-Yttrotantalite.—Orthorhombic samarskite represents the type in which Nb_2O_5 predominates; yttrotantalite that in which Ta_2O_5 predominates. Found in pegmatite at Manendrika accompanied by almandin-spessartite, beryl and hematite. The samarskite crystals are from 1 to 16 cm. in length, pitch black in color when fresh, but yellowish when hydrated. Found also at Fefena, Miakanjovato and other places. Specific gravity 5.05 to 5.6 but lowered to 4.0 by hydration.

Samirésite (see Betafite).—Isometric. The crystals are octahedral in part, very fragile and gamboge-yellow in color. Samirésite is found in pegmatite dikes with beryl at Maromaingoka hill, about 400 meters from the village of Amparafaratany near Samiresy and at Andaombatotany. The crystals are sometimes associated with brown zircon which they enclose or upon which

they are implanted; also associated with native bismuth transformed to bismutosphaerite, often concentrated with altered biotite. The same deposits contain pyromorphite formed from galena. Samirésite is rich in lead.

Thorite (Orangite).—These two tetragonal silicates are characterized by Lacroix as follows:

Thorite-color brown-yellow, brown-black, brown-red, specific gravity 4.4–4.8.
Orangite-color orange-yellow, specific gravity 5.19–5.4.

The theoretical composition (SiO_2 18.5 per cent., ThO_2 81.5 per cent.) is rarely realized, more often (uranothorite) there exists uranium, iron and sometimes a little lead and calcium. At Ambatofotsy, Lacroix found deep brown-red uranothorite always implanted on the brownish malacon, and sometimes associated with betafite. The mineral is very hydrated and monorefringent. A partial analysis by Demalander shows: ThO_2 49.2 per cent.; U_3O_8 7.0 per cent.; Ce_2O_3 3.0 per cent., with much Fe. The radioactivity compared with that of the black oxide of uranium as measured in the laboratory of Mme. Curie is 3.57.

The first specimen of orangite from Madagascar (probably from the basin of the Sahavary) was analyzed by Muguet (See No. 16 table of analyses).

Red thorite (uranothorite) from Befaritra analyzed by Pied, showed a content of 13.1 per cent. Fe_2O_3 and may be designated ferrothorite.

Fine crystals sent Lacroix from the region south of Lake Itasy, some of which attain a length of 3 cm. following the vertical axis, indicate this to be a classic region for orangite. These crystals are of a clear yellow-orange color.

At Fiadanana, Soarivola, Sambaina and elsewhere, the orangite crystals are sometimes enclosed in crystals of betafite or in aggregates of crystals of malacon. At Ambodivoandelaka, orangite crystals were noted enveloped in columbite.

Thorianite.—Thorianite is an isomorphous mixture of ThO_2 and UO_2 in proportions very variable, with small amounts of

other elements; crystallization isometric; color black to blackish-brown; transparent in thin sections, with reddish-brown color; lively luster; monorefringent; infusible B.B.; attacked by concentrated azotic and sulphuric acids, very radioactive; specific gravity 9.33.

Lacroix describes this mineral as coming from the province of Betroka, and presumes that it came from pegmatite. An analysis by Pisani shows: ThO_2 93.62 per cent.; UO_2 4.73 per cent.; Fe_2O_3 0.29 per cent. and PbO 1.80 per cent. Up to this time thorianite was known only in Ceylon.

Tscheffkinite.—This orthorhombic silico-titanate of the ceric earths shows in Madagascar a feeble radioactivity due to a small content of thorium. It is found in many places in granitic potassic pegmatite, sometimes in masses weighing several kg. It occurs also in syenitic pegmatites.

Uraninite.—In 1926 Mlle. Y. Brière[3] described uraninite as found in a potassic pegmatite at Malakialina, in the province of Fianarantsoa. This great dike forms a small hill about fifty meters in height, four hundred meters long and two hundred and fifty meters in width. This dike is intrusive in a series of mica-schists and gneisses. The uraninite was found in the detritus from a quarry, in the form of large nodules, the exterior of which is citron-yellow and the center black in color. The ore is compact but with fissures filled with products of alteration (gummite?) of a reddish orange or yellow color recalling the alteration products of fissures in the pitchblende of Katanga. These alteration products contain some silica and lead. Accessory minerals are black tourmaline, blue and yellow beryl, emerald-green apatite and columbite.

The black homogeneous part has a specific gravity of 9.42 and a radioactivity of 6.93 as compared with that of black oxide of uranium as determined by the Cheneveau-Laborde apparatus. The exterior yellow material is also very radioactive (about 7.0).

Mlle. Brière did not fine any uraninite in the pegmatite dikes which are exploited for muscovite in the district.

[3] *C. R. Acad. Sc. Paris*, vol. CLXXXII., p. 641. See also René van Aubel, *Revue de Geologie*, 1926, p. 399.

TABLE I.

ANALYSES OF MADAGASCAR URANIUM MINERALS.

%	Ampangabeite.		Autunite	Betafite.		Euxenite.		Samiresite.	Samarskite.	
No.	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.	No. 7.	No. 8.	No. 9.	No. 10.
SiO_2	.....	1.75	.....	.....	.....	.....	.....	.....	.....	.....
SnO_2	0.80	0.30	.....	0.30	0.37	.....	.....	0.10	.....	.....
TiO_2	4.90	2.10	.....	18.30	16.20	19.10	23.10	6.70	1.42	0.40
ThC_2	2.50	1.30	.....	1.30	1.12	1.54	2.80	.....	1.05	2.00
UO_2	.....	.....	.....	.....	.....	16.40	14.70	.....	8.70	20.20
UO_3	19.40	.....	62.70	26.60	27.15	.....	.....	21.20	.....	.....
U_3O_8	.....	12.50	(P_2O_5 15.50)	.....	.....	.....	.....	.....	.....	.....
Nb_2C_5	34.80	50.60		34.80	34.80	33.70	29.30	45.80	43.60	29.60
Ta_2C_5	8.90		.....	trace	1.00	.....	.....	3.70	11.15	19.20
Ce_2O_3	0.60	5.75 *	.....	.....	.....	.....	.....	.....	.....	.....
$(La, Di)_2O_3$	.....	2.10	.....	.....	.....	.....	.....	.....	.....	.....
$(Ce, La, Di)_2O_3$	.....	.....	.....	0.60	1.00	2.44	2.20	0.20	4.05	0.40
$(Yt, Er)_2O_3$	4.00	1.35	.....	0.90	.....	18.38	17.80	.....	9.50	7.20
Al_2O_3	2.10	1.20	.....	2.10	1.50	1.30	1.65	0.74	0.80	2.40
Fe_2O_3	8.60	7.20	.....	2.87	0.50	.....	.....	.....	.....	9.80
FeO	.....	.....	.....	.....	.....	1.10	2.25	1.06	5.40	.....
MnO	.....	1.53	.....	.....	.....	.....	.....	(PbO 7.35)	.....	1.00
MgO	.....	.....	.....	0.40	trace	.....	0.25	.....	.....	.....
CaO	1.50	1.83	6.10	3.45	3.12	2.27	1.90	.....	2.43	4.40
K_2O	.....	.....	.....	.....	0.38	.....	.....	0.30	.....	.....
H_2O	12.40	.....	15.70	7.60	12.50	.....	.....	12.45	11.14	3.60
Ignition	.....	11.55	.....	.....	.....	4.00	3.95	.....	.....	.....
Total	100.50	101.06	100.00	99.22	99.64	100.23	99.90	99.60	99.24	100.20
Spec. Grav.	3.97	3.35	3.05–3.19	4.17	3.75	4.89	4.79	5.24	4.25	5.17
Uranium %	16.15	10.60	52.19	22.14	22.60	14.46	12.96	17.64	7.67	17.81

* Entirely CeO_2.

URANIUM MINERALS ANALYZED (TABLE I).

No. 1: Ampangabeite—a new mineral. Analysis by Pisani; on this analysis Lacroix established his new species.
No. 2: Ampangabeite—from Ambatofotsikely—analysis by Duparc, Wunder and Sabot. The SnO_2 includes WO_3.
No. 3: Autunite.
No. 4: Betafite—a new mineral—from Ambalotara. Analysis by Pisani.
No. 5: Betafite—from Ambalahazo. Analysis by Pisani.
No. 6: Euxenite—from Ambolotara. Analysis by Pisani.
No. 7: Euxenite—from Samiresy. Analysis by Pisani.
No. 8: Samirésite—a new mineral—from Samiresy. Analysis by Pisani.
No. 9: Samarskite—from Manendrika. Analysis by Pisani.
10: Samarskite—from Fefena. Analysis by Pisani.

Xenotime.—The primary origin of the xenotime of Madagascar is not known as it has thus far been found only in alluvial deposits associated with zircon, monazite, magnetite, ilmenite, sillimanite, disthene and staurotide. The xenotime like the other minerals, undoubtedly comes from the crystalline series, gneiss, granite or pegmatite. As it sometimes contains thorium, it is presumably more or less radioactive.

Zircon (Malacon).—The malacon or altered zircon of Madagascar always possesses a feeble radioactivity due to the presence of thorium, possibly due to a mechanical mixture of thorite in the malacon.

THORIUM MINERALS ANALYZED (TABLE II).

No. 11: Allanite (Orthite) from Ambatofotsikely. Pisani, analyst. This sample remarkable for its high content of thorium.
No. 12: Fergusonite—from Beforona. Pisani, analyst.
No. 13: Fergusonite—from Fiadanana. Pisani, analyst.
No. 14: Monazite—from East of Miandrarivo. Pisani, analyst.
No. 15: Monazite—from Ambatofotsikely. Duparc, Wunder and Sabot, analysts.
No. 16: Orangite-Muguet, analyst. Locality probably basin of the river Sahavary. Contains traces of phosphorus and lead.
No. 17: Tscheffkinite—from Itrongay, west of Betroka. Pisani, analyst.
No. 18: Tscheffkinite—from Itorendrika west of Ambositra. Pisani, analyst.
No. 19: Zircon (Malacon) from Ambolotara, color brown-red. Pisani, analyst.
No. 20: Zircon (Malacon) from Ambatolampikely, color clear brown. Pisani, analyst.

TABLE II.

ANALYSES OF MADAGASCAR THORIUM MINERALS.

%	Allanite.	Fergusonite.		Monazite.		Thorite.	Tscheffkinite.		Zircon.	
No.	No. 11.	No. 12.	No. 13.	No. 14.	No. 15.	No. 16.	No. 17.	No. 18.	No. 19.	No. 20.
SiO_2	32.00	.....	.....	.....	2.87	13.00	18.60	22.80	17.40	18.10
SnO_2	.....	0.20	0.26	.....	.....	.....	.....	.....	.....	.....
TiO_2	.....	.....	0.26	.....	.....	.....	19.30	16.10	.....	.....
ZrO_2	.....	.....	0.89	.....	0.11	.....	.....	.....	57.20	59.90
ThO_2	5.60	2.07	4.85	9.15	11.23	64.56	0.83	0.57	0.80	1.16
UO_2	.....	6.15	2.12	.....	.....	.....	.....	.....	.....	.....
U_3O_8	.....	.....	.....	.....	.....	7.70	.....	.....	.....	.....
P_2O_5	.....	.....	.....	27.45	25.90	.....	.....	.....	.....	.....
Nb_2O_5	.....	50.10	34.79	.....	.....	.....	.....	.....	8.00	6.60
Ta_2O_5	.....		17.03	.....	0.24	.....	.....	.....	.....	.....
$(La, Di)_2O_3$	7.38	.....	.....	27.90	32.60	.....	21.83	5.51	.....	.....
Ce_2O_3	9.08	.....	.....	31.85	26.95	.....	22.67	33.13	.....	.....
YtO_2	0.40	.....	.....	.....	.....	.....	.....	.....	.....	.....
$(Ce, La, Di)_2O_3$	.....	6.15	4.06	.....	.....	.....	.....	.....	.....	.....
$(Yt, Er)_2O_3$	.....	31.20	27.54	2.93	0.30	.....	.....	.....	.....	.....
Al_2O_3	12.40	.....	.....	0.21	0.15	.....	3.35	7.00	5.60	2.32
Fe_2O_3	4.50	.....	.....	0.42	0.60	0.78	1.91	2.08	3.10	2.72
FeO	11.60	0.59	0.72	.....	.....	.....	8.20	4.40	.....	.....
MnO	0.50	.....	.....	.....	.....	.....	.....	.....	.....	0.20
MgO	0.54	0.37	.....	.....	.....	.....	0.60	1.10	.....	.....
CaO	15.58	1.40	2.10	.....	.....	0.95	3.30	7.20	.....	.....
H_2O	1.24	1.94	5.26	.....	.....	(H_2O + 5.74)	.....	.....	9.50	9.50
Ignition	.....	.....	.....	0.74	0.56	(H_2O − 5.30)	.....	.....	.....	.....
Total	100.82	100.17	99.88	100.65	101.51	98.03	100.59	99.89	100.60	100.50
Spec. Gravity	3.40	5.58	4.98	5.11	5.27	.....	4.49	.....	3.62	.....

RADIOACTIVITY OF THE MINERALS.

The determinations of the radioactivity of the minerals were made with the electroscope, using both gold and aluminum leaves and the radioactivity is compared with that of the black oxide of uranium taken as unity. Both the black oxide of uranium and the sample to be tested are pulverized in an agate mortar and the powder placed on two brass disks or saucers five centimeters in width and one millimeter in depth. When the minerals contain

TABLE III.

RADIOACTIVITY OF MADAGASCAR MINERALS.

	Locality.	Uranium %.	Thorium %.	Radioactivity.	Determined by
Ampangabeite	Miankanjovato	9.95	.....	0.59	.....
"	5 localities	.....	.....	0.44–0.85	.....
Betafite	Ambolotara	22.00	.....	0.87	Muguet
"	"	21.36	.....	0.85	"
"	Ambatovohangy	22.55	.....	0.80	.....
"	Ambatofotsy	19.93	.....	0.67	.....
"	Fiadanana	17.21	.....	0.69	.....
"	14 localities	.....	.....	0.37–1.00	.....
Blomstrandite	Tongafeno	15.13	.....	0.56	Muguet
"	"	.....	.....	0.62	.....
Euxenite	Fiadanana	9.28	.....	0.49	Muguet
"	E. Ankanzobe	3.53	.....	0.28	"
"	Samiresy	.....	.....	0.49	"
Fergusonite	Ambatofotsikely	5.30	.....	0.28	.....
"	5 localities	.....	.....	0.21–0.41	.....
Monazite	Ampangabe	.....	13.51	0.37	Orcel
"	Ambatofotsikely	.....	5.90	0.17	"
"	Tsarasaotra	.....	3.70	0.10	"
"	8 other samples	.....	.....	0.02–0.15	"
Orthite	Ambatofotsikely	.....	4.9	0.16	"
Priorite	3 localities	.....	.....	0.19–0.24	.....
Samarskite	Fefena	20.05	.....	1.00	.....
"	4 localities	.....	.....	0.24–0.53	Orcel and Pied.
Samirésite	Fefena	.....	.....	0.71	.....
"	Samiresy	.....	.....	0.52	.....
Thorite (Red)	2 localities	.....	.....	1.35–2.75	Orcel and Pied.
" (Orangite)	2 localities	.....	.....	1.70–2.80	" " "
Uranothorite	Ambatofotsy	5.93	43.23	3.57	Mme. Curie.

only uranium and radium, and when the layers on the disks do not exceed one millimeter in thickness, the variations of the thickness has little influence on the results obtained, but if the min-

eral contains thorium, which is the case in a very large proportion of the radioactive minerals of Madagascar, the quantity of the powdered minerals employed has a great influence on the results, and it is necessary to operate with a thin layer. The determinations given below were made mostly upon one gram of powdered mineral.

The rays *a* constitute the fundamental part of the radiations used in the apparatus. As noted elsewhere, the hydrated uranium minerals possess less radioactivity than the original minerals.

In the case of thorium minerals, which when cold, emit an emanation that is liberated more or less easily according as the substance is hydrated or not, the products of hydration become more permeable to the emanation and are consequently more radioactive than the primary mineral. The emanation produces phenomena of the same order of greatness as the two products of the ray *a*.

PARAGENESIS OF THE MINERALS.

The pegmatites exploited in Madagascar for the extraction of radioactive minerals are generally much disintegrated; often also these minerals are concentrated from the Terre Rouge. It follows that it is rare when one is able to observe them in a coherent gangue and thus establish their order of crystallization.

Samples submitted to M. Lacroix by Mr. Brusque are thus of interest. In the pegmatite of Mahatsinjo upon the banks of the Sahasarotra are found little veins limited by large plates of biotite. These veinlets are made up of a concentration of large crystals of orthite, betafite, almadin-spessartite, orangite and aggregations of smaller crystals of malacon.

These crystals are accompanied by a little smoky quartz and a very little microline in part decomposed. Some of these veinlets show an orderly arrangement of the minerals. Upon the biotite plates, for example, there is a layer 2 to 3 cm. in thickness composed of rose-gray crystals of malacon, the crystal faces pointing inward toward the middle of the veinlets, and sometimes enclosing long prisms of orangite of contemporary formation. A similar disposition of the minerals was also noted in

samples from Saorivola near Fiadanana. Then comes a layer composed of orthite, betafite and garnet. These minerals interpenetrate one another but present clear geometric forms when they are enclosed in quartz. In another deposit situated to the north of Fiadanana, the orthite is clearly enveloped by betafite. It may be noted also that malacon also occurs elsewhere in the middle part of pegmatitic dikes. From these veins one can extract coherent blocks weighing several kilograms, the minerals of which are generally much altered. The garnet is transformed into amorphous oxides of iron and manganese; the orthite is of a brown red color; the betafite is of a beautiful golden yellow and translucent on its borders; and the orangite is extremely fragile. The orangite crystals alone, when enclosed in malacon, are entirely unaltered. M. Brusque discovered in the same region blocks of euxenite weighing up to 10 kilograms and composed of crystals assembled in groups showing crystalline forms at one of their extremities. They enclose crystals of monazite and columbite.

DEPOSITS EXPLOITED.

Primary Ores.

The two primary radioactive minerals that are of economic importance in Madagascar are betafite and euxenite, but so far betafite alone has furnished any considerable tonnage. According to Hess[4] Madagascar produced in 1912 to 1923, inclusive, 80.8 metric tons of betafite. According to L. M. Jones,[5] Madagascar produced in 1924 4.9 metric tons of betafite and in 1923–24 6.6 metric tons of euxenite. Monazite has also been exploited.

The difficulty in making a market for the primary radioactive minerals of Madagascar, appears to be due to two causes; first, their special nature requires a new chemical treatment, more complex than that required for the secondary ore, autunite; and second, the presence of a small amount of thorium, the disintegration of which forms mesothorium, the radioactivity of which adds itself to that of radium. The rapid methods used in the

[4] Mineral Resources of the U. S., 1923.

[5] Mineral Resources U. S. for 1925.

measurement of radioactivity does not permit of determining the amount to be assigned to radium or to mesothorium, and the separation of the two is impossible. It results that the salts of radium containing some mesothorium become in time less radioactive and consequently of less commercial value, especially when the salts are sold for medical use.

Betafite.—The most important deposit of betafite appears to be that at Ambatofotsy exploited by M. Dreyfus. Here a pegmatite dike in gneiss has been trenched for a length of 36 meters and a depth of 16 meters, and has produced, up to 1922, 20 metric tons of betafite crystals. The pegmatite is much altered and disintegrated. It is mined by the pick, the large crystals being sorted out and the smaller extracted by washing. The pegmatite dike is in gneiss. Going from N.W. to S.E. there is a zone formed essentially of quartz and altered biotite, containing a great number of large crystals of the betafite group, one block weighing 105 kg. These groups are often traversed by hexagonal tubular cavities representing former beryl crystals. Two veins or masses of smoky quartz bleached in the croppings were noted, surrounded by plates of altered biotite, the latter enclosing crystals of betafite. Around a quartzose mass situated more to the S.E. the betafite is associated with crystals of malacon and a small amount of uranothorite. One fact, which appears constant, is the smoky aspect of the quartz when the latter is associated with the betafite, and it seems that this color may be due to radiations from radium. In reference to this it may be noted that Ellsworth found uraninite in pegmatite dikes in Ontario more abundant near smoky quartz, and feldspar taking on a deep red color when associated with euxenite.

At Amparitena (4 km. E. of Ambatofotsy) three metric tons of betafite were extracted, one block of which weighed 67 kg. This mineral here also is concentrated around large masses of quartz.

At Sama, another deposit discovered by M. Florens has been prospected, showing the same characteristics as those above described. In a trench 60 meters long, 12 meters wide and 7

meters deep has been dug in the pegmatite. The betafite here is accompanied at one point by very large crystals of orthite concentrated in the neighborhood of masses of smoky quartz or greenish biotite. Tourmaline is rare and beryl still rarer.

Euxenite.—Euxenite is the titano-niobate most widely distributed in Madagascar. In many pegmatites it is found in sufficient quantity to be considered as an ore of uranium, and the Grand Isle is the country susceptible of furnishing the greatest quantity of this mineral as well as the most beautiful specimens. It is always accompanied by muscovite, beryl and monazite, and at a few points by columbite, the crystals of which sometimes attain large dimensions. In a fresh state, the euxenite of Madagascar is black, but very frequently it is transformed by hydration, sometimes superficially, sometimes entirely, to a brown-yellow material, which has a very striking greasy luster. While the fresh mineral is not attacked by acids, the hydrated is easily attacked and the specific gravity much lowered.

In the high valley of Betsiboka in the region of Ankazobe, a great number of deposits of euxenite have been found. It occurs on Mt. Vohambohitra, at Ambohitsarabe, Ranomafana, Fiadanana, Sahamandrevo, Andibakely, Ambatofotsikely and many other places.

From the deposit at the hill of Andaombatotany, M. Rasamoel recovered from 10 cubic meters of éluvion (fragmental detritus) 280 kg. of euxenite by hand sorting.

While the mining of euxenite by itself would not at present be successful commercially, as a by-product of beryl mining it may in the future become profitable, as in Ontario, where there is a possibility of producing uraninite as a by-product of feldspar mining.

Monazite.—The discovery of the property of the oxides of the rare earths in producing a vivid incandescence when brought to a sufficient temperature, resulted in monazite becoming a mineral of practical importance, chiefly because of its content of thorium.

This mineral can also be utilized from the point of view of its radioactivity. It is not itself radioactive, but it furnishes two

varieties of mesothorium, one of which in its turn furnishes radiothorium, the radioactivity of the latter being greater than that of radium. The price of the salts of mesothorium is much less than that of the radium salts, due chiefly to the fact that activity lessens rapidly with time.

Most of the monazite is found primarily in the potassic pegmatites but in Madagascar as elsewhere it must be collected for commercial purposes from alluvials, except that a certain amount is available as a by-product in beryl mining. In the alluvium of the Saka, a tributary of the Mananjary, monazite occurs in small citron-yellow grains, rarely attaining a diameter of 1 mm., associated with zircon of the same dimensions. The sands are first washed in bateas, the concentrates being submitted to an electromagnetic treatment employing a magnetic field of growing intensity, thus sorting out successively magnetite, ilmenite, garnet and finally monazite, leaving zircon as the last product, as that is non-magnetic. By this method a product is obtained containing up to ten per cent. of thorium. Monazite is also abundant in the auriferous alluvial deposits of the smaller ranges of Amboana, north of Ihosy; in the placers of Kiravoravo and Fandrangato (valley of the Mananara, with much garnet), as well as in the placers of Volotara in the basin of the Ivoloina and elsewhere. From the point of view of radioactivity, one metric ton of monazite contains about the equivalent of 2.5 mg. of bromide of radium.

The radioactivity of the monazite was determined by M. Orcel from 14 localities, showing a value as low as 0.02 at Soarano and as high as 0.37 at Ampangabe. The monazite from the latter locality was found by M. Raoult to contain 15.38 per cent. of ThO_2. The monazite of Morarano, 70 km. northeast of Tananarive is not radioactive. These measures give an idea of the variability of the content of thorium in Madagascar monazite, and indicate that the radioactivity is proportional to the content of thorium. In 1923 Madagascar produced 1,488 kilograms of monazite.

Secondary Ores.

Autunite and uranocircite often form as coatings at the surface in the neighborhood of niobates of uranium, and such deposits are of no economic importance.

But in the drainage of the river Fitamalama about 10 km. S.S.E. of Antsirabe and a few hundred meters east of Vinaninkarena, autunite is found disseminated in peaty layers in alluvium [6] in sufficient quantity to be possibly of commercial value now or hereafter.

The Fitamalama (also written Fitatahana) after its confluence with the Manandona, has cut its bed in an alluvial deposit 20 meters in thickness, resting on a gneissic granite. These beds are composed of a horizontal succession of gravel, fine sand and argillaceous layers, with intercalated beds of peat. In general, the alluvium is quartzose containing fragments of rhyolitic pumice. The autunite or uranocircite is found in a sandy clay zone, whitish at the base in which are intercalated two beds of peat; together mineralized for a thickness of about one meter. The autunite spangles impregnate this material, particularly the peaty portions. It exists also in small amount in the underlying pegmatite and granite.

The autunite is concentrated in numerous contraction cracks, in worm holes and in cylindrical cavities resulting from the disappearance of roots. The deposit appears to be due to the precipitation by the phosphatic portion of the alluvials of small quantities of soluble salts of uranium resulting from the decomposition of uraniferous titano-niobates of the drainage basin.

M. Nelson states that the radioactivity of the sediment is greater than would be indicated by the content of autunite. It is, therefore, probable that the autunite has crystallized as a secondary mineral after having first been deposited in a colloidal state and that some of this colloidal material remains in the deposit thus increasing its radioactivity. This mode of deposit suggests an explanation of the origin of the uranium which is found in the variety of lignite in Sweden designated *Kolm*.

[6] Not a lake deposit, as stated in Mineral Resources of the U. S., 1923.

An attempt has been made to concentrate the autunite with water by the aid of shaking tables. The sorted peat ore contains about 0.5 per cent. of oxide of uranium. The mechanical treatment brings the product up to 8 or 10 per cent. On account of its lamellar structure, there is a considerable loss of the autunite. Moreover as noted above, there is probably a certain quantity of phosphate of uranium in a colloidal state in the peat which is lost in the washing process. Concentrates were produced by this method to the amount of 36,866 kg. in the years 1909–1921 inclusive.

It is probable that autunite is found in other similar deposits in the same region, and it has been collected a little farther to the south at Andranonanahary, but there the alluvials are dislocated and their mineralization unequal.

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THE OCCURRENCE AND AGE OF CERTAIN BROWN IRON ORES IN ALABAMA AND ADJACENT STATES.

GEO. I. ADAMS.

THE brown iron ore deposits of the Woodstock district at the southern end of the Birmingham Valley in Alabama have been well described by Ernest F. Burchard.[1] He recognized two types of ore: "(*a*) the main ore masses which occur with the Cretaceous clays and sands, and (*b*) the later ores which occur in Tertiary loam and gravel." The Cretaceous beds belong to the Tuscaloosa formation. The Tertiary beds were referred to the Lafayette, which was natural enough at the time, but those familiar with recent work on the "Lafayette problem" will understand that Lafayette has no very definite significance. Various surficial deposits that have been referred to it are now regarded as due to the weathering, slumping, creeping and washing of underlying formations.[2] Certain deposits in the coastal part of Alabama, that have been called Lafayette, have been studied by C. W. Cooke,[3] who regards them as distributed by ancient streams. He has assigned a probable Pliocene age to some of them.

It is possible that what Burchard called Lafayette may be in part Tertiary, but this is difficult to prove. The important point made by Burchard is that the main masses of primary brown ore in this district are of Tuscaloosa age. The presence of carbonate masses in the workings where the ore is under heavy cover implies that the iron was deposited as siderite, which has since been altered to limonite.

In the same report which contains Burchard's descriptions and conclusions, Edwin C. Eckel discusses the origin of the brown

[1] U. S. Geol. Surv., Bull. 400, p. 150 et seq., 1910.

[2] Shaw, E. W.: U. S. Geol. Surv., Prof. Paper 108, 1918.

[3] Geol. Surv. of Alabama, Special Report No. 14, p. 296, 1926.

iron ores, and seemingly basing his opinion on observations made especially in the Russellville district of northwestern Alabama, reaches the conclusion that the majority of the deposits and the bulk of the brown ores were formed during the Tertiary. His final statement is: "In the Woodstock district, for example, the evidence is less direct, but even there it is possible to say quite definitely that most of the ores were formed prior to the Lafayette deposition and later than the Cretaceous." [4] In one place [5] he inserts "late Tertiary" after Lafayette, which makes his meaning more explicit. He assigned no brown ores to the Cretaceous and he did not mention the Tuscaloosa formation in his discussion of the Russellville district. Apparently Eckel erroneously identified the Tuscaloosa as Lafayette, and this led him to a wrong conclusion in regard to the age of the iron ore. This error in regard to the Tuscaloosa seems to have misled Burchard, who has stated [6] that the thickness of the Lafayette in the Russellville district is one hundred feet plus, and that the Tuscaloosa is very thin, when in fact the Tuscaloosa reaches one hundred feet in thickness near Russellville.

This variance of opinion led me to examine the Russellville district and to compare it with the Woodstock, with which I was familiar. The primary brown ores near Russellville were found to be clearly of Tuscaloosa age, being overlain by deposits which are typical of that formation and underlain by Bangor limestone. This may be observed at several localities. The Tuscaloosa has been removed from the primary brown ores at some places. There are extensive deposits of brown ores which have been derived from the original beds and deposited at lower elevations, possibly to some extent in Eocene time, but mostly at later times. These derived deposits correspond to the second type of brown ore deposits in the Woodstock district as described by Burchard.

Although the primary ores of the two districts are of the same age, the associated formations differ in character. The under-

[4] *Op. cit.*, p. 150.

[5] *Op. cit.*, p. 149.

[6] Brown Ores of the Russellville District, Alabama, U. S. Geol. Surv., Bull 315, p. 153.

lying formation of the Russellville district is the Bangor limestone, which is of Mississippian age, while the underlying formations in the Woodstock are the Conasauga limestone of Cambrian age and the Knox dolomite of Cambro-Ordovician age. The

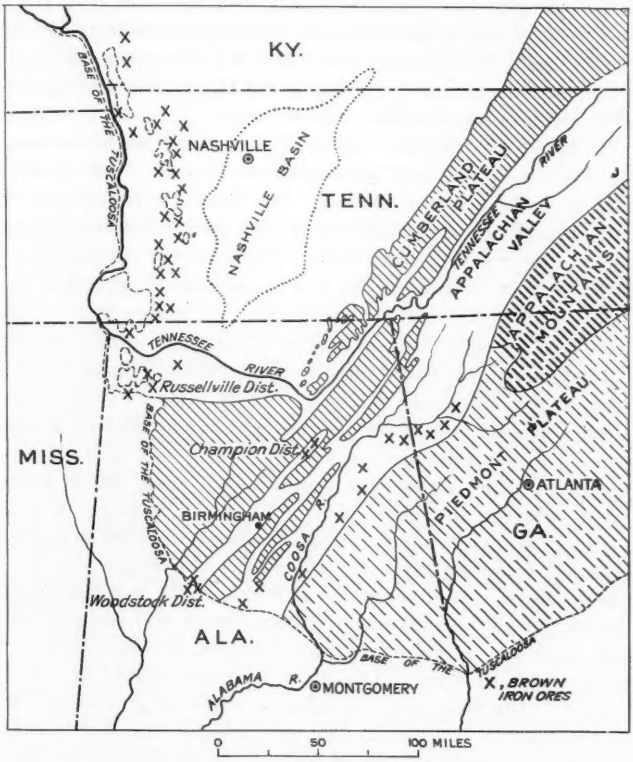

FIG. 1.

Tuscaloosa in the two districts differs in the character of the gravels; chert being common and quartz rare at Russellville, while quartz is common at Woodstock. Between Woodstock and

Russellville, the base of the Tuscaloosa carries no brown ores Their absence is probably due to the fact that in the interval the Tuscaloosa lies on the sandstones and shales of the Pottsville, since in all the localities in the region here considered, the primary brown ores of the type under discussion have been deposited where limestones or dolomites are, or have been present as the bed rock. South of Leighton, which is to the northeast of Russellville, there are brown ores lying on the Hartselle sandstone, but they belong to the secondary or "*b*" type.

In order to explain the conditions under which the brown ores of Tuscaloosa age were deposited, some points in the history of the region are here recalled. The Paleozoic formations of the Appalachian region suffered erosion during Triassic, Jurassic and Lower Cretaceous time. The materials derived from them were transported so far that no evidence of stratified deposits of them is found in Alabama, even in the deep wells which have been drilled in the southern part of the state. The youngest formation which is found resting on the Paleozoic rocks in Alabama is the Tuscaloosa of Upper Cretaceous age. It is a continental deposit, at least for the most part and particularly where it is exposed. It has been encountered in deep wells in the southern part of the state and has a thickness of 1,000 feet at some places where it has been passed through in drilling. It is a veneer of sands, gravels and clays which were deposited on a plain that was somewhat diversified by escarpments, ridges and anticlinal valleys. As it buried the Paleozoic rocks, it transgressed farther inland, well beyond its present limits, and occupied the low areas and valleys of northern Alabama, probably being irregular in distribution and thickness, especially toward its inland margin. The materials of which it is composed give some idea of the direction from which they were brought, and from studying them the conclusion may be reached that the drainage of Tuscaloosa time was probably quite different from that of the present. The surface of the Tuscaloosa was an aggraded plain continuous with a plain of degradation adjacent to the Appalachian mountains. As the Tuscaloosa was spread by the streams, the primary

deposits of the iron ores which are here under discussion were formed at certain favorable places where dolomites or limestones were the bed rock, as is exemplified by the Woodstock and Russellville districts.

With this conception of the problem, I visited the Champion brown iron ore district, which lies approximate 65 miles northeast of Woodstock and 85 miles southeast of Russellville. It is in Murphree's Valley, which is practically a continuation of Birmingham valley. After observing that the primary ores had been worked out on the ridge to the west of the ore washer at Champion, I asked Mr. R. B. Doud, general foreman, whether he knew of any considerable amount of quartz gravel in the workings and he accompanied me to a conspicuous showing of quartz gravel which was scattered where mining had removed the ore from the top of the hill. I also saw scattered quartz gravel at lower levels. Burchard [7] recorded the presence of white sand and gravel which he considered characteristic of the Lafayette, but since these were found in test pits along the northwestern margin of the deposits, they were probably at lower levels than the original brown ore. I did not see any quartz gravel overlying the primary ore, but it seems reasonable to conclude that the gravels once occupied such a position and that the ore and gravel were deposited in Tuscaloosa time. An argument for the Tuscaloosa age of the deposits is that a drainage system similar to the present or that of the Tertiary could not have brought the gravel to the locality from the rocks from which they must have been derived.

Once the brown ores were deposited at the base of the Tuscaloosa they were safely buried until Tertiary time, since the subsequent Cretaceous deposits are marine and were laid down during a subsidence that must have brought much of northeastern Alabama to such a low altitude that stream erosion was not effective where the Tuscaloosa had been deposited. With the elevation of the region in Tertiary time, the Cretaceous deposits were subjected to erosion.

[7] U. S. Geol. Surv., Bull. 400, p. 165.

The Eocene base level in the anticlinal valleys of northeastern Alabama has been placed at the level of the Intermediate Ridges which correspond with the Highland Rim peneplain. Eocene erosion probably exposed some of the brown ore deposits and possibly entirely removed some of them. Others may have been reworked and deposited near by. Weathering, creeping, slumping and particularly solution of the underlying limestones and dolomites have been effective. In the Champion district, which includes, besides the Champion mine, the older workings at Tate's Gap and newer workings which are planned to recover all the secondary deposits, the "red dirt" with shot and gravel ore may be seen on the slopes of the ridges and in alluvial deposits down to the level of the present small drainages.

Certain brown ores in Alabama are closely associated with bauxite deposits. When I first discussed the bauxite deposits with the late Dr. Eugene A. Smith, he remarked to me that any thorough study of the bauxite deposits would involve the problem of brown iron ores. In a recent paper, I have shown that the bauxites are of Eocene age.[8] Brown ores occurring in close association with them may be secondary deposits derived from those of Tuscaloosa age in Eocene time, since the stream valleys and low areas in which the basal deposits of the Tuscaloosa in northeastern Alabama were laid down were above the subsequently developed peneplain of the Intermediate Ridges on which bauxite is found. Primary deposits of iron ores of Tertiary age would be expected in the sedimentary deposits of the Coastal Plain rather than in the Appalachian region where erosion was active.

With the foregoing conclusions in mind, brown ores of Tennessee and Georgia of the type here discussed may be considered. In western Tennessee, the Mississippian limestones are overlain by patches of Tuscaloosa, which are outliers of the main area of the formation to the west. Certain brown ores of this district may reasonably be assigned to the same category as those in northwestern Alabama. There are scattered deposits between

[8] Bauxite Deposits of the Southern States, ECON. GEOL., vol. 22, No. 6, pp. 615–620, 1927.

Russellville and the Tennessee state line which serve to connect them. Burchard has recently described the deposits in western Tennessee in considerable detail but has not discussed their age.[9] There are some deposits in Kentucky which are just to the east of the outcrop of the Tuscaloosa formation which fall in line with those in western Tennessee.[9a]

The iron ores which have been classed as gossans, veins and Paleozoic bedded deposits by S. W. McCallie in his descriptions of the deposits in Georgia,[10] and also those derived directly from them are not considered here, but it seems appropriate to include deposits of brown iron ores lying in the Valley Region of northwestern Georgia, which occur under the same conditions as deposits in Alabama near Rock Run that were probably deposited in Tuscaloosa time and reworked in the Eocene, and in later times. Their geologic relations are shown in the Rome Geologic Folio by C. W. Hayes. The descriptions of those in Georgia by McCallie fit in with the ideas advanced in this article fairly well and are more detailed than will be found in the folio by Hayes. I have seen some of the deposits in Georgia and also some near Rock Run but have not studied them adequately. I have likewise seen old workings at Anniston in Alabama and at Ironaton between Anniston and Talladega and regard them as of the same class.[11] There are many notes on the brown iron ores in the report on the Valley Regions of Alabama by Henry McCalley.[12] Some of the deposits he describes are clearly not of the type here

[9] *Manufacturer's Record*, July 21, 1927, p. 69–73.

[9a] The article by J. K. Roberts on the "Tuscaloosa Formation in Kentucky" (Amer. Jour. of Science, Dec., 1927, vol. 14, pp. 465–472), which appeared while this paper was in press, confirms the statement concerning the Tuscaloosa age of these deposits.

[10] A preliminary Report on the Iron Ores of Georgia, Geol. Surv. of Georgia, Bull. No. 10–A, 1900.

[11] It is my impression that the Tuscaloosa formation was formerly well represented in the Coosa Valley region, since certain gravels which may now be found there appear to be remnants of it. In a personal communication from Dr. Charles Butts I am informed that he has noted gravels in the Coosa Valley which he has assigned provisionally to the Tuscaloosa.

[12] Report on the Valley regions of Alabama, Part I. The Tennessee Valley Region, 1896; Part II, The Coosa Valley Region, 1897; Geol. Surv. of Alabama.

discussed but others appear to be. Localities where the writer thinks the original brown ores are of Tuscaloosa age or where secondary deposits occur which have been derived from them are shown in a general way on the accompanying map. The scale will not permit showing them in detail.

In conclusion, it may be stated that the brown ores here considered are of Post-Paleozoic age. The primary deposits are of Tuscaloosa (Upper Cretaceous) age. Others are secondary deposits derived from them. Some of these may be of Eocene age, but solution, redeposition, and mechanical reworking of the primary ores has continued to the present.

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EDITORIAL

THE OPENING AS A REASON FOR ORE.

WHOEVER puts himself to the task of explaining ore will recognize the advantages of starting with conditions which are definitely known. He will find himself, therefore, instinctively paying attention to the opening in the rock which preceded the deposit of ore mineral. For the opening is the immediate, tangible reason for ore. All other reasons are either only local in application, or they fall within the speculative ground which lies beyond experimental proof. The opening is the visible culmination of distant, preparatory actions. It is the direct and almost universal cause of ore being in one place rather than in another. It does not, indeed, answer all the riddles of ore formation. But we need only to bestow a glance upon this subject to realize that the opening demands first attention in any study of the distribution of ore.

In pursuing this subject it is necessary of course to remain within the shallow zone, a few miles thick, where an opening can exist. Any block of the crust there is subjected at all times to gravity; the action of this force continues without intermission and its results, as we shall see, enter largely into the conceptions here being presented. Now, the block is composed of diverse materials, which respond to this force in very diverse ways. There are rigid masses of granite, gneiss and schist; strong but less resistant beds of quartzite; and, then, in the descending scale of strength, thick beds of dolomite, thick beds of limestone, thin beds of quartzite, dolomite and limestone, and beds of shale, thick or thin. Then, in addition, there are actual fluids, especially molten rocks, gouges and waters.

Let us start at a time when all of these rock bodies, including the fluids, occupied positions in which they were adjusted to the

general set of prevailing forces. There occurred, for some reason, a disturbance. The soft parts constituted the lubricants and mobile bodies of the system. But the rigid units might undergo only elastic deformation; or they might snap into blocks which could then ride stiffly past each other. And at every small yielding of these blocks there was an exaggerated yielding and motion of the soft material, which quickly took its portion of the readjustment, advancing for long distances into entirely new positions. The pressing of this soft material by its hard walls, and the facile shifting of the fluids along openings is the general action which includes ore formation.

This action follows the creation of openings between a region of greater and a region of smaller pressure. The region of smaller pressure is, in many cases, the earth's surface, and an obvious feature in the formation of most ore-bodies is a release of pressure by an opening of the rock extending all the way up to that surface. But there is another feature which I have learned to consider equally vital and equally common, namely, the growth of that opening during the movement of fluids through it, by the removal of rock volume in excess of the mineral volume deposited; or, in other words, by the growth of porosity during mineralization.

These two features of the rock opening, taken together, furnish certain ideas of fresh interest. They imply, to begin with, that the ore body is made under a leaky, not under a tight, cover. They give us a means, then, for thinking about the pressure of the metal-bearing fluids—a momentous subject, for, though the degree of pressure may not affect the kind of sulphide which is formed, it will determine where the sulphide-making fluid will travel, where it will pass quickly, and where it will linger. The pressure, at these shallow depths, with open cracks above, will be made up mostly of the weight of the column of moving fluid. If the fluid approaches water in composition, it will press but lightly against its walls and will even permit those walls, in openings large enough, to collapse. If it approaches molten rock in composition, it will be sufficiently heavy to sustain the walls even of large openings.

The fluids could be made to press more strongly against the walls, as by the sudden growth of forces at the source, by the transmission of these forces through a fluid of high viscosity and slow motion, or by the confinement of the fluid to conduits so small as to develop a high friction head. Such results are conceivable; and it is clear that if the fluids only press enough, they will open up spaces, concurrently with the arching, doming and thrusting of the rocks. The possibility is evident; but the question as to whether ore is actually thus formed can be answered only by the facts to be found in the field.

Any such facts, suggesting that ore fluids have pushed the walls apart, are not only few in number, but they are very dubious as to meaning. The much cited flotation of rock fragments in the ore fluid has no necessary bearing on this question; a column of mud rising in a pipe can bring up rock fragments without pushing the walls apart at all, and it can hold such fragments in suspension after it has congealed. And, although the concurrent arching, doming and thrusting ought to be clearly in evidence around very bulky mineral bodies such as those of Nacozari or Jerome, the fact is that around such bodies it has seldom been found, and then very doubtfully; and the geologists who advocate this process have had to concern themselves chiefly with much thinner things, such as quartz veins, in which the outward movement of the walls would have inconspicuous effects and in which it would be incapable of proof or disproof. There are, on the other hand, various bulky mineral bodies whose roofs have been depressed, during the process of mineralization, tens or hundreds of feet below their normal positions. And the number of such cases, as search is made for them, rapidly increases.

The actual ore body structures, when yielding any evidence at all, indicate, then, that the walls, instead of generally moving apart during mineralization, actually come toward each other. These ore bodies, and most ore bodies in fact, are highly porous and the growth of porosity is not open to question. Indeed, a weakening of the structure by growth of porosity is a necessary part of the ore genesis. If there were no such growth, if there

were no change, or if there were a decrease, the ore would be closely confined to the original openings, which seldom were more than mere cracks, and it would be dispersed along those openings, rather than concentrated at certain spots. Accessibility to the altering agents is a major variant in the alteration of rocks, and a bed of quartzite so constituted and situated that it will sag, crack and open toward a conduit filled with travelling ore fluid, is more favored to make ore than a block of limestone which lies insulated and survives unbroken. The distinguishing quality of a favorable rock may from this standpoint be regarded as its ability to become more porous when it is mineralized. The increase in porosity and therefore of accessibility, which we find in all but a few cases, is the only known means by which, through the travel of low gravity fluid along cracks, the concentration which we term an ore-shoot can be formed. The fluid, moving along these cracks, at first slowly and between fresh rock walls, gradually alters and renders more porous the walls along the way; it removes more solids than it deposits and, like a stream cutting down a dam, at length so opens its channel that it can pass onward in a flood. The ore, once made, constitutes a sponge-like enlargement of the original conduit, and its wide-spread vugs and cracks give it a porosity thousands of times as great as that of the rock which it replaces. So large a volume of rock substance is, indeed, removed, and the structure is therefore so far weakened, that the overlying rock is sometimes undermined and made to subside in the manner already mentioned. And in this way numerous additional cracks, of very small displacement, are created quite outside and beyond the cracks which otherwise would exist. This is the means by which the disseminated ore bodies, for example, seem to have been made. It is a general means by which new rock is broken in the course of the mineralizing action, and by which ore shoots can continue to grow larger so long as the metal-bearing fluid continues to pass through.

This process, of openings reaching the surface and supplying to the rock along the way a metal-bearing fluid which alters the rock with increase of porosity, is found to bring together various

peculiarities of ore bodies which are not otherwise coördinated. The preference of ore for calcitic and feldspathic rocks, for example, is seen to be due to their particular brittleness and strength, and at the same time to their capacity for alteration with increase of porosity. The scheme accords with the fact that ore so commonly follows fractures of minor displacement instead of the associated structural faults. It gives a reason for the usual cementation of broken ore minerals by later ore minerals. In a large way, it gives a reason for the proximity of mineral deposits to igneous intrusions; for not only are the borders of the rigid igneous rocks, loci of openings, but, to go farther back, the intrusions and the ore-carrying agents, both mobile fluids, will converge after a disturbance toward the same place, which is in fact the region of smaller pressure. It gives a reason likewise for the proximity of mineral deposits to certain kinds of gouges; for it creates an expectation that the removal of the soluble parts of the rock will create silica-alumina sludges and that these sludges will squirt along the cracks opened by the settling of ground in the course of mineralization. And lastly, this way of thinking about ore affords relief from a dilemma which has appeared in the past few years. The geological facts suggest a column of metal-bearing water extending from a magma reservoir to the surface. But from laboratory experiment it is reasoned that such a column of water must by its weight be forced down into the reservoir, and it is reasoned, therefore, that any juvenile water involved in ore-formation must have ascended as a tenuous gas. So it must, in fact, if the walls of the reservoir were self-supporting. Those walls, however, are not self-supporting; according to our best knowledge, they rest, with the weight of the overlying cover, against the magma which they envelop, and they keep that magma at a pressure overwhelmingly adequate, when a continuous opening occurs, to prevent the water from draining back into the reservoir, and to force it up to the surface.

When we concentrate on the opening as a reason for ore, we make of ore genesis a structural problem, and a problem of the strength of materials. We do not at once find out where the

metal ultimately came from. But the clarity with which that limitation becomes evident shows the advantage of the method; realizing that the broken rock masses are flooded with unstable fluids, among which the ore-bearers are merely incidental, we cannot expect to pick out a definite source of the metal and a path of travel from a region whose physical qualities are only beginning to be understood. We find ourselves able, on the other hand, to use the opening as a reality about which the explanation of ore can be centered and from which it can be extended outward by experiment and induction.

AUGUSTUS LOCKE.

DISCUSSION AND INFORMAL COMMUNICATIONS

A SIMPLE APPARATUS FOR HEAVY MINERAL SEPARATION.

Sir: The accompanying diagram (Fig. 1a) illustrates a simple piece of apparatus used in the separation of heavy minerals from concentrates, for the purpose of sedimentary analysis or drill hole correlations. The method of using is as follows:

The tube is two thirds filled with bromoform and the concentrate introduced into the wide limb *A*, which is then corked so that the surface of the bromoform rises to the open end of the narrow limb *B*. (A little manipulation is required here.) The tube is next jerked sideways—not shaken up and down—until the concentrate is uniformly distributed in *A*, care being taken that the lower limits of the lighter-than-bromoform grains are not jerked round the bend into *B*. After thorough disturbance, separation is allowed to take place, the tube being held in such

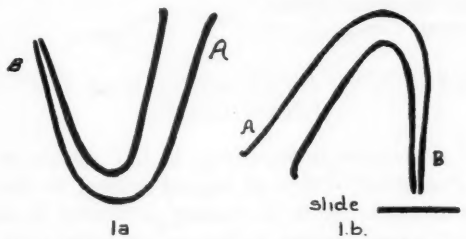

FIG. 1. Simple bromoform separation apparatus. One half actual size.

a position that the wider limb *A* is vertical. The lighter portion of the concentrate having accumulated at the top of the liquid in *A*, the process is repeated until the separation of the heavier-than-bromoform grains in the bend of the tube is complete. As-

suming the operator to be facing the tube as figured, the tube is slowly turned in an anticlockwise direction until the narrow limb *B* is vertical, with the "jet" end a quarter of an inch over a microscope slide, as in Fig. 1b. Any tendency to choking of the jet by reason of a large accumulation of heavy grains is obviated by pushing in the cork slightly so that a drop falls on to the slide. At this stage, slight tilting of the tube dislodges any grains from the walls. When no more grains are seen to fall down to the jet, the expulsion of two or three drops on to the slide, by pushing the cork in farther, completes the separation of the heavy minerals, which are now ready for drying and mounting.

The above method enables a separation to be carried on with the minimum amount of bromoform, and the apparatus is easily made—an important fact when numbers of separates have to be made. For handling larger amounts of concentrates, the size of the tube may be proportionately increased, but a fairly long experience has shown the size as indicated in the accompanying figure to be the most satisfactory. It will be noted that a tube of this size is *per se* only of use when dealing with concentrates such as are obtained by panning.

F. J. FRASER.

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UNDERGROUND PHOTOGRAPHY—A DEPTH OF FOCUS CHART

Sir: A recent paper in this *Journal* by L. C. Graton on Underground Photography[1] was of especial interest to the present writer in its application to the making of pictures in caverns, a problem of present concern to him in connection with the examination of dam sites. With most of the views presented by Professor Graton he is wholly in accord. However, the question of depth of focus in relation to aperture appears to merit further

[1] "Underground Photography without Flash Light," ECON. GEOL., vol. 22, No. 4, pp. 388–399, 1927.

discussion and elaboration in the form of the accompanying chart.

In the paper mentioned, the statement on page 392, lines 10 to 4 from the bottom, while true, is somewhat misleading. To the writer, it carries the tacit suggestion that any solution other than an experimental one is impracticable or unduly laborious. As a matter of fact, this problem of relation of focal depth to aperture in its elementary form involves the simplest geometrical optics and no more abstruse arithmetic than proportion. Given cases may easily be worked out approximately by mental arithmetic at the outcrop or more complete analytic or graphic solutions may be arranged in various ways, of which the chart here presented is an example.

The rudiments of the problem are illustrated in Fig. 1. The simple formula for the foci of lenses is

$$\frac{1}{F} = \frac{1}{f_0} + \frac{1}{f_i},$$

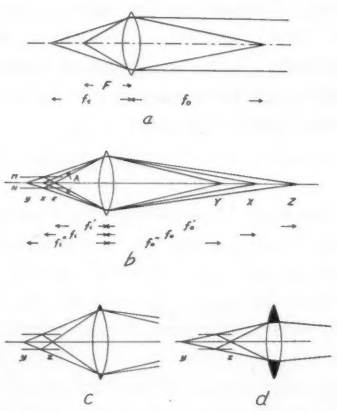

FIG. 1. Diagrams to illustrate focal relations derived in the text. (*a*) Shows relationships of foci in simple lens. (*b*) Indicates the development of depth when permissible limits of diffusion are adopted. (*c*) Showing depth of focus with large aperture. (*d*) Under conditions identical with (*c*) showing increase in depth with decrease in aperture.

F being the focal length of the lens, *i.e.*, one of the pair of conjugate foci of which the other is infinity, and f_o and f_i being the focal distances to object and image respectively (Fig. 1*a*). For theoretically perfect focus there is no depth and only objects precisely in the true object plane will focus in the image plane. For practical purposes it is conceded that sharp definition is achieved when the circle of diffusion over which light from a true point is dispersed is not over 1/200 inch in diameter. Granting a practical limit in this way the relations shown in figure 1*b* hold.

X and x are the positions of the principal object and its image respectively. The distance MN is the diameter of the allowable circle of diffusion, greatly exaggerated. Y and Z are the limiting positions of objects nearer and farther than X which produce cones of rays impinging on the image plane in a circle not exceeding the size MN and y and z are the true foci corresponding to these. It is evident that the distances xy and xz and hence the distances XY and XZ depend on the angle A, being greater as A is smaller. See Figs. 1*c* and 1*d*. The angle A is determined by the working aperture. YZ is the depth of focus. Assuming a fixed focal position, aperture and diameter of circle of diffusion (D) the following equations govern:

$$f_i' = f_i - \frac{D}{2 \tan \frac{A}{2}}.$$

But

$$2 \tan \frac{A}{2} = \frac{\text{Aperture}}{F} = \frac{1}{F \text{ number}}.$$

Then

$$f_i' = f_i - D \ (F \text{ number of aperture})$$

and similarly

$$f_i'' = f_i + D \ (F \text{ number of aperture}).$$

Then

$$f_0'' = \frac{1}{\frac{1}{F} - \frac{1}{f_i - D\ (F \text{ number})}}$$

and

$$f_0'' \frac{1}{\frac{1}{F} - \frac{1}{f_i + D\ (F \text{ number})}}$$

and

$$YZ = \frac{1}{\frac{1}{F} - \frac{1}{f_i - D(F \text{ number})}} - \frac{1}{\frac{1}{F} - \frac{1}{f_i + D(F \text{ number})}}$$

Using these relations the accompanying chart (Fig. 2) has been constructed. Certain assumptions and simplifications have been resorted to in order to cast the chart into straight line form. These are as follows:

1. The circle of diffusion is 1/200 inch for an 8-inch lens and corresponding smaller for shorter focus lenses so that negatives made with these have proportionately superior definition (insofar as this factor is concerned) and may be enlarged to correspond with 8-inch focus.

2. The F number used is the ratio of the actual working focus to the working aperture so that for a given F number the angle A is constant. Except for very near objects this consideration may be ignored and the nominal F numbers used.

3. The designations on the fundamental scales in the chart are the object distances in terms of the focal length as a unit. The distances on the same scale are the corresponding image distances in the same unit,[2] this artifice producing the linearity of the iso-aperture lines. The auxiliary chart below the main chart is provided to convert distances in feet into focal units and vice versa.

[2] Wentworth, C. K., "Photographic Practice for Field Geologists." Iowa Studies in Natural History, Univ. of Iowa, vol. XI., No. 4, p. 34, 1925.

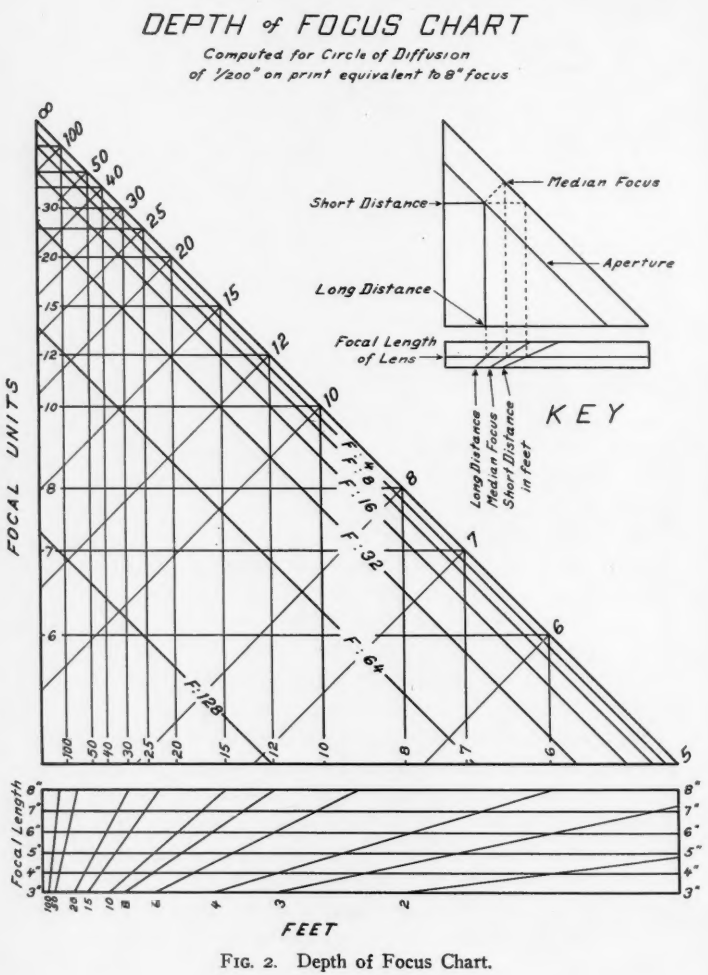

FIG. 2. Depth of Focus Chart.

Directions for using chart.

Given two objects, one near and one far. To find median focus and maximum aperture.

(*a*) Find the long distance in feet at bottom, follow obliquely to focal length thence vertically to intersection with (*b*).

(*b*) Find short distance in feet at bottom follow obliquely to focal length thence vertically to diagonal margin of chart and then horizontally to intersection with (*a*).

(*c*) At this intersection (*a*) and (*b*) read aperture on heavy diagonals in *F* numbers and from it follow light diagonals to upper right margin and read focus in focal units on scale. To convert to feet follow vertically down to focal length and thence obliquely to left to scale of feet at bottom.

Example: It is desired to include objects ranging from 40 feet to 6 feet distant with sharp definition and minimum exposure. Forty feet converted to focal units (of a 6″ lens) becomes 80; six feet becomes 12 units. The horizontal 12 unit line and the vertical 80 unit line interpolated intersect at just under *F*:64, possibly *F*:61. This position traced to the upper left along the light diagonals reads about 20.5 focal units and this in turn is converted by the auxiliary chart to 10.75 feet. Hence the focus should be set at 10.75 feet approximately and an aperture of about *F*:61 used with such exposure time as is required by this and other considerations.

The chart may be used to find the focal setting and the aperture which will be needed to span two extreme objects at different distances or may be used to solve various other related problems. If definition less perfect than 1/200 inch will serve, somewhat greater extremes of nearness and farness will be encompassed by a given aperture.

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A PHYSICO-CHEMICAL THEORY OF METASOMATISM.

Sir: In number 5 of volume 22 (August, 1927), V. M. Goldschmidt replies to my further criticism of his views on the above subject.

I regret to say that he fails to convince me of the soundness of his generalization to which I took exception; in addition he appears to have lost sight of the essential point in my criticism.

In his latest reply, Mr. Goldschmidt suggests that I am "unaware of the fact," in the example of double decomposition given by me, "that the reaction will give another solid product quite neglected by Mr. Boydell, and that product is solid $Ca(OH)_2$." That lime would react (under the same conditions with regard to water as were specified) with water according to the equation

$$CaO\ (solid) + H_2O = Ca(OH)_2\ (solid)$$

is of course certain and hardly requires mention, but under the conditions specified by myself for the example given, the conversion to $Ca(OH)_2$ would proceed to completion and proceed so rapidly that there would be practically only one solid phase, $Ca(OH)_2$ to wit. The "substance added," viz. H_2SO_4, would then attack the $Ca(OH)_2$ according to the reaction

$$H_2SO_4 + Ca(OH)_2\ (solid) = CaSO_4\ (solid) + 2H_2O,$$

the equilibrium expression being

$$[H_2SO_4] = \frac{[CaSO_4]}{[Ca(OH)_2]} \cdot k_2 = K_2, \qquad (a)$$

which has the same form as

$$H_2SO_4 + CaO\ (Solid) = CaSO_4\ (Solid) + H_2O$$

$$[H_2SO_4] = \frac{[CaSO_4]}{[CaO]} \cdot k_1 = K_1, \qquad (b)$$

and again parallels Mr. Goldschmidt's case of

$$[\text{Alkali silicate}] = \frac{[\text{feldspar}]}{[\text{mica}]} \cdot k = K,$$

the form of which he claims to be peculiar to metasomatism.

Mr. Goldschmidt's statement (p. 521) ". . . that Mr. Boydell seems unaware of the fact that metasomatism means the transformation of a solid mineral (or several solid minerals) to another solid mineral (or minerals) by means of solutions (or gaseous phases) under such conditions that the products are formed in the presence of the educts" is, besides being incorrect,

unnecessary as it seems to me, seeing that I have recently [1] discussed the mechanism of metasomatism at considerable length.

Mr. Goldschmidt is in error in his statement (p. 521) that I claim ". . . the formation of a solid product in such a case is dependent on the concentration of two components, not on the concentration of one component," as I have not made such a claim. He apparently is unaware of the fact that he is merely quoting himself (vol. 21, p. 91) in that matter.

In equation (*a*), to use Mr. Goldschmidt's words and in connection with a case of double decomposition and not of metasomatism (replacement), " one of the educts " and " one of the products " of the reaction are co-existing as solid phases during its progress and a minimum concentration of the " added substance," H_2SO_4, is manifestly required in order that $CaSO_4$ may be deposited. Since Mr. Goldschmidt has stated in connection with equation (*a*), which has the same form as (*b*) that ". . . if the concentration of the active substance (in the case quoted H_2SO_4) is less than that minimum, no mineral replacement will result . . ." and has consistently claimed that this necessity for minimum concentration of the added substance is peculiar to the reactions involved in metasomatism, I submit that in showing it applies to a case of double decomposition, as illustrated in (*a*) or (*b*) not involved in metasomatism, I have made good my contention that this conditional precipitation is common to all cases of double decomposition comparable to those involved in metasomatism, and is not in any way peculiar merely to those connected with metasomatism.

I would further point out that the type of reaction given both by Mr. Goldschmidt for metasomatism and myself for ordinary double decomposition is merely characteristic of those reactions in which at least one of the original substances and one of the products of reaction are what is commonly called " insoluble substances " and that the fact that has mislead Mr. Goldschmidt in this matter is that such " insoluble substances " are those commonly involved in metasomatism.

[1] " A Discussion of Metasomatism and the Linear Force of Growing Crystals," ECON. GEOL., vol. 21, pp. 1–55, 1926.

Mr. Goldschmidt's concluding statement, "It is just the difference between metasomatism (mineral replacement) and other processes of mineral formation (as crystallization from ordinary solutions or from magmas) that the range of concentration of the liquid (or gaseous) phase is restricted by the presence of more than one mineral partaking in the reaction. This restriction of the variability of the liquid phase makes the difference between the physical chemistry of metasomatism and the physicochemistry of other processes of mineral formation"—particularly the last sentence, appears to me to call for comment. In view of the fact, pointed out by myself [2] that we do not know the nature of the variables involved in metasomatism and cannot usually define the system, Mr. Goldschmidt's conclusion is an unjustifiable extrapolation and an attempt to generalize where, in the present state of our knowledge, any such generalization can only be misleading. It is all the more so in this case seeing that Mr. Goldschmidt makes the verisimilitude of an appeal to the Phase Rule in a way likely to mislead geologists whose acquaintance with physical chemistry is too slight to enable them to see the fallacy involved.

H. C. BOYDELL.

GEOLOGICAL DEPARTMENT,
MASSACHUSETTS INSTITUTE OF TECHNOLOGY,
CAMBRIDGE, MASS.

[2] *Op. cit.*, p. 4.

REVIEWS

Summary of Mineral Production in Foreign Countries, 1920–1924. By L. M. JONES. U. S. Bureau of Mines, Mineral Resources of the United States, part 1, pp. 441–516, 1925.

Prior to the War, there were three outstanding sources of information concerning the production of minerals throughout the world, (1) the annual report of the Chief Inspector of Mines of Great Britain, officially recorded as "Mines and Quarries, Part V, Colonial and Foreign Statistics," but commonly known in the industries as the "British Blue Book," (2) the annual report, "Mineral Resources of the United States," published by the U. S. Geological Survey in which much of the foreign statistical material was derived from the British Blue Book, and (3) the "Mineral Industry," published annually since 1892 by the McGraw-Hill Book Company of New York and its predecessors. Probably the publication of the Metallische Gesellschaft should be mentioned, for even though it was concerned only with the metals, the statistics were largely obtained privately and were widely regarded as more accurate than some official publications.

The war stimulated widespread interest in mineral production throughout the world and soon thereafter the U. S. Geological Survey issued a pamphlet entitled "Summary of Mineral Production in Foreign Countries, 1919–1920," based in part on official publications but in large part on reports from authorized foreign governmental agencies and from U. S. Consular agents abroad. In the recent report for the years, 1920 to 1924, the work has been further amplified to include brief statements concerning the mineral resources of many countries which issue no reports. This report contains either tabular or text summaries of mineral production or resources for 128 countries or colonial possessions. In the opinion of the reviewer, it is the most comprehensive, exhaustive, and accurate report on the subject that is now available. The author, Miss Lucy M. Jones, deserves considerable credit for the care and thought shown in its preparation. With the increase in interest in foreign mineral resources, the report should meet a widespread demand.

D. F. HEWETT.

U. S. GEOLOGICAL SURVEY,
WASHINGTON, D. C.

Methods of Applied Geophysics for the Exploration of Oil, Ores, and Other Useful Deposits. By ERICH PAUTSCH. Published privately by the author, Houston, Texas, 1927. 82 pages with numerous diagrams.

This small book in its few pages covers: I. The Methods and tasks of applied geophysics; II. The gravitational method, with a brief discussion of the elements of the theory of gravitation and a more extended discussion of the theory of the Eötvös torsion balance method with some of the more basic formulæ and with profiles of the gradient and differential curvature produced by different types of bodies; III. The seismic and acoustic methods, a discussion principally of the theoretical principles of (pure rather than applied) seimology and with an inadequate description of the instruments actually in use; IV. The Magnetic method, theory, and instruments, a very brief description and discussion; V. The electric methods, a brief history of the use of electric methods and a discussion of the galvanometric method, the inductive method, the theory and description of the current in the earth method, resistance of some conducting bodies method, the (wireless) wave method, the capacity method, and the polarization method.

The book is one that will be needed in the reference library of geophysics, as it is the only book in English that attempts to cover this subject and as Dr. Pautsch apparently has sound knowledge of the theory of pure geophysics. Yet the discussions are so condensed and brief that the beginner will doubtfully follow and understand the discussion, and the advanced student of geophysics will not find it of much use. The English of the book is marred by many non-idiomatic words and expressions, which, however, should be forgiven Dr. Pautsch when it is realized that he had known English only a few months when he wrote the English version of the book.

DONALD C. BARTON.

HOUSTON,
TEXAS.

The Earth and Its Rhythms. By CHAS. SCHUCHERT and CLARA M. LEVENE. xvi + 410 pages. Illustrated with many figures. D. Appleton & Co., New York, 1927. Price $4.00.

It is rarely that a book of "popular science" is at the same time readable and accurate. This little book with its suggestive title is an exception. It is interesting reading and at the same time is good science. The authors do not depend upon sensationalism to secure attention. They give a simple account of the making of the earth, in terms that are easily understood by the non-technical reader and in a narrative style that is pleasing and convincing. Its reader realizes that he is scanning

the words of experts, who are not trying to force their views upon a sceptical world, but are trying to tell in plain language some of the wonderful facts that have been learned by geologists who have attempted to decipher the past history of the earth and discover the processes by which it has reached its present condition. The authors have done their work well. Their little volume is an interesting story of the birth and growth of the earth and its inhabitants. It embodies the best thought of many geologists and declares their mature judgments. It is a book that can be put into the hands of any intelligent person with the certainty that it will be read and read with interest and profit. It is well printed and exceptionally well illustrated with half-tones and sketches. It is especially valuable to those who wish to obtain a knowledge of modern geological thought without being bothered with technical detail.

W. S. B.

Locating Minerals and Petroleum. A Series of Articles on the Theory and Practical Use of the Eötvös Torsion Balance. By H. SHAW and E. LANCASTER JONES. Republished by L. Oertling, Ltd., London, 1927, from articles in *The Mining Magazine*, April to July, 1927. 40 pages.

The paper gives a description of the Eötvös torsion balance and its manipulation as particularly illustrated by the Oertling balance; torsion wires; a brief derivation of the fundamental formulæ; the gravity effects produced by particular attracting bodies, with an outline of the derivation of the formulæ for the immediate and distant effects of topography; the formulæ for the gradient and differential curvature effects due to infinite horizontal slabs with a rectangular cross section, for infinite horizontal slabs with an inclined face; the graphs of the gradient and differential curvature profiles produced by an infinite horizontal slab, an infinite vertical step, a similar inclined step, an isostatic block, an infinite rectangular horizontal block, and an approximation to an anticline; a discussion of isograms and their construction; the reproduction of several torsion balance maps, including one showing the results of an interesting study by the authors of the gravity anomalies of their basement laboratory, where, as the expert but not the beginner would expect, the gradient is away from and not toward the walls. The paper ends with a practical example of the complete calculations for a single station.

This paper is more or less parallel to the manual published by L. Oertling, Ltd. The two papers are authoritative and are by far the best discussions in English on the theory and application of the Eötvös torsion balance. This paper should be in the hands of all torsion balance observers and of all geologists, physicists, and executives who wish to know about the torsion balance.

HOUSTON, TEXAS. DONALD C. BARTON.

Clays, Their Occurrence, Properties and Uses. By HEINRICH RIES. Third Edition, revised and enlarged; pp. 613; figs. 173. John Wiley & Sons, New York. Price $7.00.

The appearance of a third edition of this well-known book is welcomed by every student of clays. Dr. Ries is unquestionably the leading ceramic authority at the present time, and the third edition of his book brings together in compact and readily accessible form a great mass of data, much of which has appeared since the second edition was published.

An interesting chapter on the chemistry of clays should prove useful, as methods of analysis are described. In the following chapter the reviewer was particularly pleased to find a brief resumé of the more recent studies of clay colloids. A timely addition is a section on bentonite.

The discussion of the distribution of clay in the United States and Canada by States and Provinces is perhaps too generalized to be of service to those working in any particular locality, while it is too detailed for the general student. However, the references that follow the discussion of the distribution in each State are extremely valuable, since they give access to detailed literature for those desiring it.

Few will feel the loss of the sections on clay mining and manufacture, particularly the latter. But the reviewer does feel that more space could have been given to the origin and occurrence of clay.

The publishers have made an excellent book; the print is clear, the illustrations and diagrams lucid and the binding serviceable.

G. T. WICKWIRE.

YALE UNIVERSITY,
NEW HAVEN, CONN.

Beiträge zur Kenntnis der Manganerzlagerstätte von Tschiaturi im Kaukasus. By WILHELM DE LA SAUCE. *Abhandl. z. prakt. Geol. und Bergw.*, Band 8. 90 pp., 7 text fig., 8 Pl., bibliography and index. Wilhelm Knapp, Halle, 1926. Price 6.60 marks.

The manganese deposits of Tschiaturi, on the southwest slope of the Caucasus, are fully discussed and illustrated, with especial attention to the geological history and formation of the region, and an account of the working, including the details of the present Harriman concession. Tables of analyses and comparative statistics are appended.

BOOKS RECEIVED

A Quantitative Mineralogical and Chemical Classification of Igneous Rocks. By EDWIN T. HODGE. Univ. of Oregon Pub., vol. 1, No. 2, 1927. Mostly published before.

Die magnetischen Verfahren der Angewandten Geophysik. By HANS HAALCK. Pp. 150. Gebrüder Borntraeger, Berlin, 1927. Price, 12 marks.

Geologisches Praktikum. By RUDOLF SOKOL. Pp. 248, 127 figs. Gebrüder Borntraeger, Berlin, 1927. Price, 14.50 marks. Field geology, methods, and instruments.

Observations on the Mineral Constitution of the Broken Hill Lode. By F. L. STILLWELL. Aust. Inst. Min. & Met., N. S. 64, 1926, pp. 97–172. 15 plates, 16 figs. Mineralographic study; many uncommon minerals.

Abhandlungen zur praktischen Geologie und Bergwirtschaftslehre. Edited by DR. GEORG BERG. Wilhelm Knapp, Halle.

Band 9. **Die Rolle kolloider Vorgänge bei der Erz- und Mineral-Bildung Inbesondere auf den Lagerstätten der hydrosilikatischen Nickelerze.** By W. SCHORNSTEIN. Price, 5 marks.

Band 10. **Die Devonischen Eisenerze des Mittelharzes.** By J. HESEMANN. Price, 3.50 marks.

Band 11. **Eine Studie über den Braun-Juraβ im nordöstlichen Schwaben und seine Eisenoölithflöze.** By FRIEDRICH SCHLEH. Pp. 43. Price, 4.80 marks.

Band 12. **Petrographische Untersuchung über die Eignung von Graniten als Strassenbaumaterial.** By WILHELM ZELTER. Pp. 75. Price, 5.30 marks.

Band 13. **Über die Bildung der Alaunschiefer und die Enstehung der Kieslagerstätten Meggen und Rammelsburg.** By GEORG FREBOLD. Pp. 121, 47 figs. Price, 8.60 marks.

SOCIETY OF ECONOMIC GEOLOGISTS

The seventh Annual Meeting of the Society of Economic Geologists was held on December 30, 1927, at Cleveland, Ohio, with the Geological Society of America, by invitation of Western Reserve University and the Case School of Applied Science.

At the business meeting preceding the technical session, the election of officers was announced as follows:

President: W. H. Emmons; Vice-President: H. S. Gale; Councilors (term expires 1929) B. S. Butler, W. E. Wrather, David White.

The following new members were declared by the Council to be elected:

E. L. Bruce, Ontario Dept. of Mines, 98 Bagot St., Kingston, Ont., Canada.

Edwin E. Ellis, President, Universal Exploration Co., 71 Broadway, New York City.

M. H. Gidel, 526 Hennessy Building, Butte, Montana.

Thomas L. Gledhill, Ontario Dept. of Mines, Parliament Bldgs., Toronto, Canada.

Albert O. Hayes, Rutgers University, New Brunswick, N. J.

R. N. Hunt, 506 Title Insurance Building, Los Angeles, Calif.

Carl Lausen, Arizona Bureau of Mines, Tucson, Ariz.

F. A. Linforth, 1140 W. Platinum Street, Butte, Mont.

Hugh M. Roberts, 306 Lonsdale Building, Duluth, Minn.

F. A. R. Stappenbeck, Werder (Havel), Kemmitzer Str. 50, Germany.

Bohuslav Stoces, Mining University, Vysoka Skola Banska, Pribram, Czechoslovakia.

The second award of the Penrose Medal of the Society of Economic Geologists was made this year to Prof. J. H. L. Vogt of Norway for his outstanding contributions to the Science of Economic Geology and as an indication of the respect with which he and his work are held by economic geologists throughout the world.

The following resolution has been passed by the Council: "The Nominating Committee shall contain one member of the Council of the preceding year."

The following papers were presented:

Presidential Address, F. L. Ransome, Directions of Progress in Economic Geology.

W. Lindgren and J. G. Greveling, The Ores of Potosi, Bolivia.

H. G. Ferguson, Age and Distribution of Nevada's Ore Deposits.

E. S. Moore, Origin of the Pre-Cambrian Banded Iron Formations.

T. M. Broderick, Results of Geophysical Explorations in the Michigan Copper Country.

Edward Sampson, May Chromite Crystallize Late?

C. S. Ross, The Hydrothermal Origin of Chromite.

G. F. Loughlin, Remarks on Certain Unsatisfactory Concrete Aggregates.

Ralph Arnold, Hazards of the Oil Industry. (Read by title.)

R. E. Somers, Petrographic Criteria of Structure in the Cromwell Oil Field, Oklahoma.

The meeting was well attended, eighty-one persons signing the register.

The above papers, if accepted for publication by the Society, will appear in this Journal from time to time as they are received from the authors.

SCIENTIFIC NOTES AND NEWS

D. F. Hewett, of the U. S. Geological Survey, has been elected president of the Geological Society of Washington.

F. L. Ransome has completed his work at Jerome, Arizona, and will be at the California Institute of Technology, Pasadena, for the remainder of the year.

R. W. Brock and A. F. Rogers came from the Pacific Coast to attend the meeting of the Geological Society of America at Cleveland, Ohio.

J. W. Furness, formerly of the Bureau of Mines, Canada Geological Survey, is now the head of the recently created Minerals Division of the Bureau of Foreign and Domestic Commerce.

C. S. Butler, of the U. S. Geological Survey, and formerly with the Calumet and Hecla Mining Company, has completed a survey of the State of Colorado, and has now gone to Tucson, Arizona, where he is temporarily professor of Economic Geology at the University of Arizona.

T. B. Nolan, of the U. S. Geological Survey, was married December 3d in Washington, D. C., to Miss Mabelle Orleman, daughter of Dr. Daisy O. Robinson.

J. B. Tyrrell recently gave $10,000 to the Geological Society of London to enable British geologists from time to time to examine at first hand the geology of Canada.

J. W. Finch is lecturing on mining geology at the Colorado School of Mines, and will give a course during the second semester on "The Geology of Foreign Oil Fields."

George H. Ashley delivered an address before Section E, Association of American Geographers, at Nashville, Tenn., in December, on "Geology and the World at Large."

A. A. McKay, of Alderson, McKay and Armstrong, mining engineers of Montreal, is managing director of the Amulet, in the Rouyn area of Quebec, and his firm are acting as consulting engineers for the Rhyolite Rouyn Mines.

James E. Pemberthy, who was with the Phelps Dodge Corporation at Nacozari, Sonora, Mexico, and later was manager of the Teziutlan Copper Company, has taken a position with the Katanga Company of the Belgian Congo.

Frederick G. Clapp is in Persia on professional business.

B. V. Lombard, of the Transvaal University College, has been appointed junior geologist of the Geological Survey of South Africa, taking the place left vacant by the resignation of Dr. P. A. Wagner.

Douglas G. H. Wright, consulting engineer and geologist, has moved his office from the Royal Bank Building to 304 McKinnon Building, Toronto.

Charles Rees, geologist of the Vanadium Corporation of America, has recently returned after twenty months spent in investigating the mineral resources of Africa.

H. W. Turner is examining mining properties in eastern California and western Nevada.

C. P. McCormack, consulting mining engineer for Crowell & Murray, of Cleveland, Ohio, has sailed for Russia to investigate iron ore mines.

Lionel C. Ball, deputy chief of the Queensland Geological Survey and state petroleum geologist, is a member of the Oil Advisory Board of Queensland.

E. F. Wilson is examining a large placer area in Fresno, Colombia, for the Ludlum Engineering Corporation.

William Burns, formerly on the engineering staff of the Phelps Dodge Corporation at Bisbee, Arizona, is now manager of the N'Changa Copper Mines, Ltd., of Northern Rhodesia.

Frank Cameron, formerly with the Braden Copper Company, Rancagua, Chile, is now mine superintendent with the Patino Mines & Enterprises Consolidated Co.

H. J. Steiny is head of the geological office of the Associated Oil Company at Los Angeles and supervisor of the company's geologists in California and Colorado.

Capt. M. E. Odell, of Toronto, Canada, addressed the Washington Academy of Sciences at Washington in December, on the scientific aspects of the 1924 Mount Everest expedition.

Leslie Urquhart and D. P. Mitchell have gone from London to Queensland to visit the Mount Isa holdings of the Russo-Asiatic Consolidated.

J. B. Scott, recently field manager at the Bowanza Mine, Mitta Mitta, Victoria, Australia, is now State Mining Engineer for Tasmania.

Henry F. Lefevre is in Colombia examining placer propertes for the Ludlum Engineering Corporation, and later will do some investigation work in Brazil.

W. H. Stronge and H. C. Stotesbury have gone from Sydney, Australia, to Papua, where an inspecting party is surveying for the Australian Commonwealth and the Anglo-Persian Oil Company.

The American Association of Petroleum Geologists will hold their Thirteenth Annual meeting in San Francisco (Clift Hotel) March 21–23, with field trips from Los Angeles on March 24 and 25. Further information will be sent out later. Advance inquiries may be sent to J. T. Wood, Associated Oil Company, 79 New Montgomery Street, San Francisco.

At the meeting of the Geology Section of the Northwest Scientific Association, held in Spokane, Wash., December 28–29, Professor V. R. D. Kirkham acting as chairman, the following papers of interest to economic geologists were read: (1) Bottoming of Ore Deposits in the Coeur d'Alene Mining District: Discussion led by J. H. Eby, Spokane, Wash. (2) Existence of Large Tonnage Ore Deposits in Stevens and Pend Oreille Counties, J. H. Eby, Spokane. (3) Economic Geography of Hawaii, O. W. Freeman, State Normal School, Cheney, Wash. (4) Notes on the Geology of the Chewelah Quadrangle, R. H. B. Jones, State College, Pullman, Wash. (5) Major Structural Features of Idaho, V. R. D. Kirkham, University of Idaho, Moscow.

The Geological Society of America held its Fortieth Annual meeting at Cleveland, Ohio, December 29–31. The Mineralogical and Paleontological Societies and the Society of Economic Geologists also held meetings. It was the most largely attended meeting of recent years. The meetings were held in the buildings of both Case School and Western Reserve University, and the Womens' Dormitories were available for sleeping quarters. The local members tendered a complimentary smoker at the Case Club, preceded by the Presidential address by Arthur Keith on the "Structural Symmetry of North America." The annual banquet was held at the Hotel Cleveland, and A. C. Lane as toastmaster brought many hearty laughs. The speakers were Arthur Keith, Bailey Willis, W. T. Schaller, Alan Bateman, Ernest Howe, and R. C. Moore. President Keith presented the Society's Penrose Medal to Professor T. C. Chamberlain, who made a vigorous reply. Afterwards he received the congratulations of the members.

Some 100 papers were presented before the Geological Society; 33 before the Mineralogical Society; 15 before the Paleontological Society, and 10 before the Society of Economic Geologists. The addresses of the presidents of the three affiliated societies were presented in joint sessions with the Geological Society of America, and were: Austin F. Rogers, Mineralogical Society, Natural History of the Silica Minerals; W. A. Parks, Paleontological Society, Some Reflections on Paleontology; F. L. Ransome, Society of Economic Geologists, Directions of Progress in Economic Geology.